William Herbert Hobbs

On

Some Principles of Seismic Geology

With an Introduction

by

Eduard Suess

With 1 plate and 10 figures in text

The

Geotectonic and Geodynamic Aspects of Calabria and Northeastern Sicily

A Study in Orientation

With an Introduction

by the

Count de Montessus de Ballore

With 10 plates and 3 figures in text

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VIII.

On Some Principles of Seismic Geology.

By

William Herbert Hobbs.

United States Geological Survey.

With an Introduction

by

Eduard Suess,

President of the Academy of Sciences, Vienna.

With plate II and 10 text figures.

Vorwort von Professor Eduard Suess.

Wer vor etwa dreissig Jahren sich über das Wesen der Erdbeben unterrichten wollte, fand in den Handbüchern der Geologie manche Angaben über die Verluste an Menschenleben, über die Bildung von Spalten, über vertikale und drehende Stösse und ähnliche Einzelheiten, aber mit Ausnahme sehr allgemeiner Hinweise auf die feuerspeienden Berge, kaum irgend eine die Ursache der Erschütterung betreffende Vermutung. So wie aber der menschliche Geist, in seinem Bestreben, das Unbekannte zu erfassen, aus wenig Kennzeichen zuerst ein schematisches Bild tastend sich schafft, entstand dann zuerst die Vorstellung von einem Epizentrum, d. i. einem Ausgangspunkte von unbekanntem Umrisse, dessèn Lage und dessen Tiefe zu ermitteln waren. In grossen Ellipsen suchte man die Verbreitung des Stosses auf Karten darzustellen. Bald zeigte sich, dass das Epizentrum nicht immer in der Mitte einer solchen Kurve lag, oder dass zwei Epizentra hervortreten. Dann lehrte die Erfahrung, dass die-

selben Ausgangsstellen der Erschütterungen nach Jahrhunderten neuerdings tätig wurden und man begann von habituellen Stosspunkten zu sprechen.

Die Fortschritte, welche gleichzeitig in betreff des Baues der Gebirge erzielt wurden, liessen erkennen, dass diese habituellen Stosspunkte in bestimmten Beziehungen zur Struktur des betreffenden Gebirges standen, dass sie oft auf Linien geordnet seien, und sogar auf solchen Linien wandern. Endlich wurden aus den habituellen Stosspunkten an nicht wenig Stellen habituelle Linien gefunden, welche sich als die Projektion von Dislokationsflächen auf die Erdoberfläche darstellten.

Der Begriff eines Epizentrums trat zurück; die Aufgabe der Ermittelung der Tiefe wurde, da es sich um die Bewegungen auf einer Fläche, vielleicht sogar auf mehreren Flächen handelte, eine völlig veränderte. Man lernte zweierlei Beben zu unterscheiden, nämlich tektonische Beben, die den Vorgang der Gebirgsbildung oder des Einbruches begleiten, und die selteneren Explosiv- oder vulkanischen Stösse.

Zur selben Zeit entwickelte sich nach dem Ersinnen empfindlicher Instrumente das Studium der Fortpflanzung der Erschütterungswellen. Es gestaltet sich allmählich zu einem selbständigen Zweige der Forschung, der bereits wichtige Ergebnisse für die Kenntnis der Tiefen des Erdkörpers erzielt hat und weitere Ergebnisse verspricht. Auf diesem Wege trennt sich die makroseismische Forschung an Ort und Stelle von der mikroseismischen an entfernten Observatorien. Die erste verlangt sehr genaue tektonische Ortskenntnis, lässt sich in keiner Weise zentralisieren und sucht die Ursachen der tektonischen Erdbeben an den Dislokationen selbst; für die zweite sind die Erdbeben vielmehr die gelegentliche Auslösung von sekundären Erscheinungen, welche sich über andere Fragen der Geophysik leicht verbreiten.

Wenige Teile der Erdoberfläche mögen für unmittelbare makroseismische Beobachtung besser geeignet sein, als Kalabrien und das nordöstliche Sizilien. Hier konnte sogar der Versuch gemacht werden, ein weiteres Element, die Schwere, mit in Betracht zu ziehen. Es muss als ein erfreulicher Umstand bezeichnet werden, dass gerade in dieser Phase der Entwickelung der Studien und bald nach einem neuerlichen verheerenden Erdbeben ein so erfahrener und ausserhalb der europäischen Schulen stehender Forscher wie Professor Hobbs aus Madison in diese Landstriche gelangt ist. Unter dem Eindrucke

der letzten Katastrophe, welche er in die Einzelheiten zu verfolgen Gelegenheit hatte, wurde Professor Hobbs zu einer Überschau der neueren Bestrebungen und Ergebnisse geführt. Gerade weil noch lange nicht über alle einschlägigen Fragen Einmütigkeit herrscht, ist das Urteil eines Unbefangenen von Wert.

Wien, März 1906.

E. Suess.

Author's Introduction.

Inasmuch as the author's nearer acquaintance with seismology dates from the Calabrian earthquake of September 8, 1905; he owes an apology for printing a paper which deals so largely with that subject. His justification must lie in the fact that the subject has been treated in its relations to the architecture of the earth's crust; for with this subject his close attention has been engaged now more than a score of years. The field of his labors, the New England province of the United States, yields to no other that has been carefully studied in the obscurity of its geologic structure; and from the wide divergence of the views evolved concerning it, and the persistency with which each has been defended, it has become widely known as the "Battle-field of American Geology".

Baffled in repeated attempts to fit the data derived from conventional methods of study to the facts actually observed in the field, the author was forced to go far aside from trodden paths and to evolve entirely new methods, before the key to the architecture of the region could be discovered.

The conclusion to which he was finally led on the basis of these later studies, may be summed up in a single sentence, to wit: upon the system of folds within the rock formations of the province there has been superimposed a system (network) of faults such as is known to exist within the Newark areas which are enclosed. If well founded, this conclusion has far-reaching consequences, for it involves the necessity of a resurvey of other portions of the Atlantic coastal province from New England to the Gulf of Mexico,— and with much probability other regions as well. The author's brief paper giving in outline the new methods employed and the conclusions based upon them, have met with stout opposition; and the completed monograph submitted at Washington for publication by the United States Geo-

logical Survey has after a long delay been now definitely refused publication by the Geologist in Charge of Geology.

In an endeavour to obtain additional light upon the problem of crustal architecture the writer's attention was turned to Southern Italy, which more than any other province seemed to offer a promise of important results. Calabria is not only a region of crystalline rocks which have been thrown into complex folds, but it has been conclusively shown to be intersected by a great number of faults. We possess, moreover, a complete series of excellent topographic and geologic maps for the province; and to this advantage must be added the seismic disturbances which indicate that earth movements are there still in progress.

That the most disastrous Calabrian earthquake for more than a century should have occurred while the author was on his way to the province, was — for him — a most unexpected good fortune; since he was thus enabled to note upon the ground the seismic and geologic correspondences.

The results of the study in so far as they relate to Calabria are given in the following monograph. The more general conclusions regarding the nature and cause of earthquakes which have been the direct result of the inquiry are here treated separately.

The fields which today offer greatest promise of extending our knowledge, are those which lie along the common border of two sciences; or, better expressed, where the arbitrary provinces of science overlap; and it is to be hoped that this common ground of geology and seismology will be more thoroughly exploited.

Written as these monographs have been in a foreign land; it is a pleasure to make acknowledgement of the courtesies extended by the Royal Italian Academy of Science (*Accademia dei Lincei*), by the Italian Geographic Society, by the Central Office for Meteorology, and by the Italian Geological Survey; in allowing the author the use of maps and books with all the privileges accorded to their own members. To Professors *Palazzo*, *Agamennone*, *Baldacci*, *Riccò* and *Monti;* his special thanks are due.

From Professor *Eduard Suess*, the distinguished founder of the science of Comparative Geology the author has received his inspiration. Though burdened with years and with the arduous labors necessary to complete his monumental work, *Das Antlitz der Erde*, Professor *Suess* has generously given of his time and from a storehouse of ripe knowledge which it is rare indeed to find. He has critically read

the greater part of the work and has contributed an introduction. The chapters which conclude the series have been evolved as a postscript after the appearance of *Les Tremblements de Terre*, upon which great work they are so largely founded. It is, therefore, a special satisfaction to be able to here record the sympathetic appreciation which they have found with the Count de Montessus. The value of his friendly criticism through extended correspondence and in the reading of the completed manuscripts, the author would gratefully acknowledge.

Rome, Italy, March 20th., 1906.

William Herbert Hobbs.

Chapter I.

Surface distribution of seismic intensity.

In order to supplement the results of the following monograph upon the structural lines of Calabria by certain additional data there have been entered on pl. of that paper the areal geology of the firmer and more elastic formations [1]) (whose boundaries are significant structural and topographic lines), while the loosely consolidated Post-Silurian formations have been left blank. The locations of the damaged communes from the earthquake of 1894 are represented by small stars and spots, which indicate also in a broad way the relative intensity of the shocks. Thanks to Director *Palazzo* and Professor *Monti* of the *Ufficio Centrale di Meteorologia e Geodinamica* at Rome, the writer has been permitted to consult the mail reports collected and filed after this earthquake. On the basis of these reports a rough threefold gradation of intensity has been adopted. Wherever structures were reported thrown down, a star of five rays was entered upon the map. Where many and large *lesioni* were reported a four-rayed star was entered, and where few and small fissures only were produced in buildings a circular spot was the symbol used. The number of communes of

[1]) *E. Cortese,* Descrizione geologica della Calabria, Mem. desc. della carta Geol. d'Italia, vol. 9, 1895, pp. XXVIII and 310, map and plates.

this third category has been somewhat augmented from the data given by *Baratta*[1]) and *Mercalli*[2]).

The generalizations regarding the surface distribution of seismic intensity may be concisely stated as follows:

1. There is in the arrangement of damaged communes no indication of a relationship between seismic intensity and distance from any point or points.

2. A tendency of the damaged communes to be arranged in essentially right lines (seismotectonic lines) is noteworthy.

3. The seismotectonic lines betray a relationship to geologic boundaries, to coast lines, to borders of mountain masses, and to other earth lineaments.

4. Damaged communes of the higher orders are quite generally located at or near the intersections of indicated seismotectonic lines.

5. The seismotectonic lines often intersect lines of volcanoes (volcanotectonic lines) at volcanic vents.

6. Seismotectonic lines reveal a tendency to appear in essentially parallel series.

The conclusions from the above observations, are that the destructive violence of an earthquake is localized on vertical planes of fracture within the earth's crust; along which cracks the seismic waves are transmitted with the least loss of intensity.

We are fortunate in possessing a very valuable series of observations brought together by Mercalli after the earthquake of November 16th. 1894, the one chosen for our illustration[3]). These

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1) *M. Baratta,* I terrimoti d'ltalia, Turin, 1901.

2) *G. Mercalli,* I terremoti della Calabria meridionale e del messinese. Mem. di mat. e di Fis. della Soc. Ital. delle Scienze, 3, ser., vol. II, 1898 (Pt. 3), I terremoti calabro-messinesi cominciati il 16 nov. 1894, pp. 228—264, pl. 2, Fig. 5.

3) Messina, east-west (first shock), east southeast-west southwest, north northeast-south southwest; Reggio Calabria, north-south, north 20° east-south 20° west, north 70° east-south 70° west, east southeast-west southwest; Gallico, north northeast-south southwest; Villa San Giovanni, north-south, east northeast-west southwest; Bagnara, northeast-southwest, northwest-southeast; Scilla, northeast-southwest, north 75° west-south 75° east; Palmi, east northeast-west, southwest, south southeast-north northwest, east-west; Seminara, north northwest-south southeast (first phase), west-east; Melicuccà, northwest-southeast; Sinopoli, west northwest-east southeast; Oppido Mamertina, north-south (first phase), east-west; S. Eufemia d'Aspromonte, northwest-southeast, north-south, east-west; Varapodio, northeast-southwest, northwest-southeast; Tresilico, north northwest-south southeast (first phase), east northeast-west southwest; S. Giorgio Morgeto, south-north; Tiriolo, northeast-southwest; Catania, northeast-southwest. (*G. Mercalli,* I terre-

data relate to the directions of heaviest shocks determined at a considerable number of points within the disturbed district. These data *Mercalli* has plotted upon a map and drawn the conclusion that they indicate the position of epicentrums, one to the northwest of Montalto d'Aspromonte between Plati and Delianuova and another in the sea between Palmi and Cape Peloro a few kilometers from the coast. The writer has entered the sama data upon his map of this earthquake (see plate II) and been led to a wholly different conclusion: namely that the directions of shocks registered at the different localities are the directions of the fissures — the seismotectonic lines — which pass through or near those localities. This will, it is thought, be apparent from examination of the map.

In surface directions at right angles to fracture lines the destructive intensity of the waves falls off rapidly, and at distances exceeding a mile has for all save earthquakes of the first order of intensity (above IX of the *Rossi-Forel* scale) small effect upon well-built structures. If these deductions be warranted by the observations, it should be possible to determine the localities of greater immunity within an earthquake region, and there to locate communes. It is, however, a fact of tragic interest that the more important places have quite generally been located just where the danger is the ereatest, and for sufficiently obvious reasons. The coast line, and gspecially its slight indentations, has naturally been first selected. Away from the sea, communes have in Italy at least, been generally established either upon the tops of low hills or upon the steep slopes and near the base of mountain masses. The principal reason for this has been the protection afforded by precipitous slopes in an age when man was particularly predatory in his habits. An additional reason for the selection may be found in the fact that the olive, fig, and vine, are the principal agricultural assets, and grow with especial luxuriance in such neighbourhoods. It is of considerable interest to note that some Italian communes have been relocated after their almost total destruction by earthquakes; and in some cases, at least, they have through a chance selection secured a more stable foundation. As a consequence of the earthquake of 1905 many Calabrian towns must be largely rebuilt, and it is of prime importance that a new site should be selected.

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moti della Calabria meridionale e del messinese. Mem. di mat. e di Fis. della Soc. Ital. delle Scienze, 3. ser., vol. II, 1898 [Pt. 3, I terremoti calabro-messinesi cominciati il 16 nov. 1894] pp. 228—264, pl. 2, Fig. 5.)

It is impossible to avoid the conclusion that the seismotectonic lines indicated upon the map are lines of fracture, from the relation indicated to geologic boundaries and to earth linaments[1]). As long ago as 1872 *Suess* showed[2]) that the coast lines of Southern Italy are for the most part lines of faults. *Cortese*[3]) in his recent monograph upon Calabria, not only confirms *Suess's* earlier determinations, but shows that a network of faults intersects the peninsula in many directions.

It is a fact well known that faults are only in a relatively small proportion of the instances possible of determination by purely structural-geologic methods; and the difficulty increases in direct ratio with the presence of complex folded structures. It is probably largely due to this fact that areas occupied by crystalline schists have in so few instances been found to be intersected by fault lines, since no reason is apparent why they should enjoy this immunity. It would appear from the above described studies upon the surface distribution of seismic intensity, that the crustal movements which produce earthquakes, search out the hidden planes of dislocations and project them upon the earth's surface with no less of definiteness than do the X rays upon the properly sensitized plate the concealed bony frameworks of our bodies.

To consider a few of the more prominent seismotectonic lines of that portion of the Calabro-Sicilian province here brought under consideration, it is observed that for Sicily the number is relatively small. In addition to the well-known fault forming the eastern coast line from Messina to Riposto, there is the line parallel to the northern coast and running from Messina to Patti and Naso, which has been shaken at the time of all the earthquakes of 1693, 1783, 1823, 1892, 1893, 1894 and 1898. Of nearly equal importance is the line which crosses the island from the sharp promontory north of Patti to the equally sharp but shorter one at Riposto upon the eastern coast. This latter line not only bounds the great Etna block upon the northeast, but it outlines the schist and gneiss masses of the sland save for a few fragments lying to the westward of Patti.

1) *William Herbert Hobbs,* The lineaments of the Atlantic border region. Bull. Geol. Soc. Am., vol. 15, 1904, pp. 483—506, plates 45—47. *Also,* Intern. Geogr. Congr., St. Louis, 1904, pp. 193—203.

2) *Ed. Suess,* Über den Bau der italienischen Halbinsel. Sitzungsb. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., vol. 65, 1872, I. Abt., pp. 1—5.

3) *E. Cortese,* Descrizione geologica della Calabria. Mem. desc. della Carta Geol. d' Italia, vol. 9, 1895, pp. 28 and 310, map and pls.

The southern border of the Peloritanian mass composed of Aspromonte gneiss, is brought out as a tectonic line, which, beginning at Roccella Valdemone includes the communes of high seismicity, Itala, Reggio, Plati, Gerace, Siderno, and Roccella Ionica; the latter upon the shores of the Ionian sea. The western margins of the Peloritani mass and of Etna are outlined by a fracture which passes through the communes of Roccella Valdemone, Randazzo, and Bronte.

In Calabria in addition to the Reggio-Plati-Roccella Ionica seismotectonic line, the great fault of the western coast from Bagnara northward, and the line from Messina eastward to Oppido are the most noteworthy. The last mentioned line has had a sufficiently tragic history. In every great earthquake which has affected its neighbourhood it has been marked out by great destruction and appalling loss of life, many thousand victims being counted in 1783. It was along this line, also, that some of the larger clefts were produced at the surface of the ground.

The statement so often made that the earthquakes of Calabria have seemed to come from the Lipari islands, would be sufficiently explained by the map, which indicates that a number of the seismotectonic lines of the peninsula when extended intersect near the craters of Stromboli, Lipari, Vulcano, and in the group of volcanic relics of which Panaria is the largest fragment. The lateral translation of volcanic vents upon the island of Vulcano long ago pointed out by *Judd*[1]), appears to have been along a fracture which passes through Milazzo and Scaletta. The former position of the crater is ahout on the line joining Randazzo to Patti.

A line of investigation which should be fruitful of results is the accurate mapping of the "craterlets" which so often arise on sandy areas in connection with earthquakes. The Calabrian earthquake of 1783 furnished a vast number of such funnels, which generally mark the outlets of water. From what is now known of the connection of springs with fault intersections, it is probable that craterlets project upon the surface such intersections either formed or considerably widened at the time of the earthquake[2]).

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1) *John W. Judd,* Volcanoes, Intern. Science series, London, 1881, pp. 178, 195—196. See also *Cortese,* Descrizione geologico-petrografico delle isole Eolie, Mem. descr. della Carta geol. d' Italia, vol. 7, 1892, p. 46.

2) 21st Ann. Rept. U. S. Geol. Survey, Pt. III, p. 91—93, pl. 8. *E. M. Shepard,* The New Madrid Earthquake, Jour. Geol., vol. 13, 1905, pp. 45—62.

Chapter II.

The passing of the centrum theory of earthquakes.

A quarter of century ago, there were few geologists who did not ascribe earthquake shocks either to the explosion of confined gases, or to the relief of upwardly directed stresses induced by confined magmas — in either case to volcanic sources of energy. Though recognized today that lighter earthquakes do sometimes occur at the time of volcanic eruptions (just as they arise from mine explosions and from collapses in caverns), and though studies by Suess[1]) and Milne[2]) indicate that a general relation in time may exist between periods of greater extravasation of lava from volcanoes and greater seisms; there is a no less general consensus of opinion that by far the greater number of earthquakes, and all macroseisms, are to be ascribed to movements on planes of dislocation, and are thus causally quite independent of action at the moment in volcanoes. It has even been shown by Milne that the central portions of Japan where many active volcanoes are located, are singularly free from earthquakes.

It was, however, in this volcanic theory of seisms that the idea of an earthquake focus, origin, or centrum had its birth; and it was the laborious investigation by *Mallet* undertaken after the Italian earthquake of 1857[3]), which gave definite shape to the theory lately so generally accepted. *Mallet's* theory was based upon the measurement of *lesioni* or fractures in wrecked structures, from which definite angles of emergence of the destructive shocks were deduced, and the centrum located by plotting upon a map and averaging the result. It is hardly necessary to state here the arguments which have been successfully made by *Neumayr*[4]) and others against the deductions of *Mallet*, since an examination of his diagram shows no central locus whatever, the many individual determinations of the centrum ranging with noteworthy uniformity between depths of 10000 and 45000 feet upon the so-called *seismic vertical*[5]).

Says *Mallet:*

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1) *Ed. Suess,* Die Erdbeben des südlichen Italien. Denkschr. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., vol. 34, 1872, pp. 1—32, 3 pls.

2) *John Milne,* The Geographical Journal, London, vol. 21, 1903, p. 15.

3) *Robert Mallet,* The Neapolitan earthquake of 1857, 2 vols., London, 1862.

4) *M. Neumayr,* Erdgeschichte, vol. 1, p. 303.

5) l. c., vol. 2, p. 251.

"The probable vertical depth of the focal cavity itself does not exceed 3 geographical miles, or 18225 feet, at the outside".

The long survival of *Mallet's* theory is due not so much to belief in the correctness of his methods, as to support given it by *Halies Seebach's* method, which is based upon the times of arrival of shock at the different observing points within an affected district. From such observations a series of annular, more or less circular or elliptical, curves are drawn called isoseismals, and the epicentrum located near the center of the innermost. This method is, as, among others, Hoernes as shown[1]), not only very crude because of the lack of sufficiently accurate observations: but it generally fails to give the direction of the shock, the instant of whose advent at the station is recorded. Should two or more shocks proceed from different loci — as is doubtless generally the case — the use of the method must result in hopeless confusion.

To draw an illustration from the earthquake country best known to the writer, we may consider the disturbance of 1894 (the latest of the quakes to have been fully described) and find how little is the evidence of a centrum[2]).

The map of *Riccò* shows that this earthquake was regarded as polycentric, with two origins (one double) in southern Calabria, and two in Sicily far to the South of Etna. The method itself clearly makes it impossible to place the seismic data in correspondence with the geology, but we may consider the element of harmony in the data applied the support the theory.

The depth of the centrum has been estimated by *Riccò* with use of all the available methods[3]), and the results are certainly significant. Attempting the use of *Mallet's* method it was found that of 33 oblique fractures in structures, there were 16 whose normals pointed in the general direction of the epicentral area, and 17 that pointed in contrary directions. The method was therefore found unavailable[4]).

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1) *R. Hoernes,* Erdbebenbunde, Leipzig 1893, pp. 141—147.

2) *Annibale Riccò,* Riassunto della sismografia del terremoto del 16 novembre, 1894 in Calabria e Sicilia. Boll. della Soc. Sismol. Italiana, vol. 5, 1899—90, pp. 157—180.

Also *Mario Baratta,* I terremoti d'Italia. Turin, 1901, pp. 567—572.

3) *A. Riccò,* Riassunto della sismografia del terremoto del 16 Novembre 1894. Rendiconti R. Accad. Lincei, Ser. V, classe di scienze fisiche mat. e nat., vol. 8, 2 Sem., 1899, pp. 3—12, 35—45.

4) In a later chapter the significance of these data will be again referred to The data used upon the author's map are a different series compiled by Mercalli.

By the method of hyperbolas the depth of 159 kilometers was obtained for the centrum. By *Dutton's* method four values, respectively 21, 26, 47, and 161 kilometers, resulted; while by a fourth method based solely upon the supposed diminution in the intensity of the shocks with the square of their distance from the epicentrum, values were obtained respectively 52, 54, 50, and 52 kilometers, in which latter values *Riccò* seems to place most confidence.

In a personal letter from which the writer is permitted to quote, Professor *Suess* writes: "The time when it was sufficient to draw some large elliptical or cyclical curves over the country and seek the depth of a centrum from the steepness of emergence on broken walls, is happily past". The recent literature indicates however, that habit is strong; and that change in method lags far behind a revolution in theory. The greatest work upon the seismo-geography of a single province, which has ever been carried to completion, has lately been issued by a veteran worker in a classical field; but in his treatment there is little indication that the origins of earthquake shocks are other than veritable points[1]). In England the newest of earthquake theories has been announced and elucidated by a pair of overlapping circular discs[2]). *Dutton* in criticising the incompleteness of certain earthquake maps says[3]); "at the present time it is considered necessary that seismic maps should show, if possible, the locations of epicenters".

When successive quakings within the same province have been localized especially upon a principal fissure, the epicenters have often been found to lie along the line of the fissure with the isoseismals extended in the same direction. This is illustrated to particularly good advantage in the study by *Weber* of the recent earthquake of Chemakha, Turkestan[4]).

For statistical seismo-geographical studies like those of de Montessus, the conception of the epicenter has been of value; since, as the locality where shocks are most violent, it is apt to be near the geographic center of the district affected[5]).

1) *Mario Baratta,* I terremoti d'Italia, Saggio di storia geografia e bibliografia sismica italiana. With 136 maps in the text, Turin, 1901, pp. 950.

2) *Dr. Charles Davison,* Twin earthquakes. Quart. Journ. Geol. Soc., London, vol. 61, 1905, pp. 18—34.

3) *C. E. Dutton,* Earthquakes in the light of the new seismology, 1904.

4) V. Weber, The earthquake of Chemakha of January 31 (February 13), 1902. Mem. Com. Géol., N. S., Nr. 9, 1903 (In Russian).

5) "On the seismic map, finished in the manner above indicated, one

In adapting the centrum theory of earthquakes to later acquired knowledge, some writers, like Baratta, have spoken of polycentric earthquakes, which in German speaking countries have been referred to as *Schwarmbeben.* The terms mesocentric area and epifocal area have also come into use; but in general, a tendency has been apparent to look at earthquakes more from the mathematical and physical, than from the geological and structural point of view.

In bringing to the fore the structural geologic aspects of earthquakes, we owe most to Austrian and Japanese workers; though a better picture of an earthquake was given by *Gilbert* in 1884[1]), than had been presented by any who had preceded him. Suess, the pioneer in so many fields, showed in 1873[2]) that the earthquakes of lower Austria have been localized along three lines of fracture (the Kamp line, the Mürz line, and the Warm Spring line). This paper has been the starting point of the now well established Austrian methods of investigation, which aim above all else to place the seismic geography of a district *en rapport* with its geologic structure.

In discussing below the surface dislocations in connection with earthquakes[3]), it will be shown that these can only be explained by movements of the crust individualized as blocks. This block or *Schollen* idea, derived from the study of the destruction wrought, but without the advantage of local surface fissuring, has been brought out by *Leonhard* and *Volz*[4]) in their study of the earthquake of 1895 in Middle Silesia. They say:

"*We must, therefore, regard the cause of the earthquake of June 11th, 1895, as a movement of the Nimpt complex of orographic blocks, which occurred along the southern and eastern fracture margins*".

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perceives that the centers of shocks, at least for the countries where seisms are frequent or simply frequent enough, are not distributed, at random: they are grouped more or less regularly in parcels *(par paquets),* we may say". (*De Montessus.* Introduction à un essai de description sismique du globe et mesure de la sismicité. Beitr. z. Geophysik vol. 4, 1900, p. 344).

1) *G. K. Gilbert,* A theory of the earthquakes of the Great Basin, with a practical application. Am. Jour. Sci., 3rd ser., vol. 27, 1884, pp. 49—53.

2) *Ed. Suess,* Die Erdbeben Niederösterreichs. Denkschr. d. k. Akad. d. Wiss. z. Wien, Math.-naturw. Kl., vol. 33, 1873, pp. 1—38, maps.

3) See p. a later chapter.

4) *R. Leonhard und Volz,* Das mittelschlesische Erdbeben von 11. Juni 1895. Zeitschr. d. Ges. f. Erdk. z. Berlin, vol. 31, 1896, pp. 1—21, map.

In the same year this idea was expressed by Thoroddsen[1]) and given a more striking demonstration, thanks to the numerous visible surface dislocations and the localization of successive heavier shocks upon individual blocks outlined by these fissures. Printed in the Icelandic language, the publication of this most remarkable paper to the world practically dates from the appearance of the German abstract in 1901.

Chapter III.

The origin of brontidi and their distribution.

The instability of the Italian peninsula is annually attested by about ten earthquakes (average for 1888 to 1898), which affect larger or smaller portions of the country. Quite as convincing a reminder, now that they have been traced to their source, are the deep rumblings which are commonly enough perceived in certain looalities, and which have generally been supposed to be either the distant roarings of the sea or the premonitory heraldings of approaching storms. The supposed origin of these sounds accounts for their common designation among the *contadini* as *marina*.

The late Professor *Cancani* of the *Ufficio Centrale di Meteorologica e Geodinamica* at Rome, collected and studied the data from this source, and showed conclusively[2]) that these rumblings, which are most frequently heard in the twilight hours or during the night when the country is most quiet; cannot be traced to the sea, to the weather, or to any artificial causes, and must be subterranean in their origin. He says:

"The acoustic characteristics of the rumblings cited above from Isernia, from the Lazial district, from Umbria, and from Cosenza; correspond perfectly with those of the rumblings that immediately precede or accompany shocks of earthquakes, and together with which therefore there is no doubt of their seismic origin" (p. 30).

The frequency and importance of earthquake rumblings has been greatly underestimated; as has been clearly shown by *Cancani*, who in the work cited has brought together the data upon the seismic

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1) Geogr. Tidskr. (Copenhagen) vol. 15, p. 93. Pet. Mitth., vol. 48, 1901, p. 53.

2) *Adolfo Cancani,* Rombi sismici. Boll. della Soc. Sismol. Ital., vol. 7, 1901—1902, pp. 23—47. See also by the same author, ***Barisal-guns — Mistpoeffers — marina.*** Ibid., vol. 3, 1897, pp. 222—284.

rumblings in Italy. It is found that they have been reported from by far the greater number of quakes.

The rumblings heard at other times Dr. *Cancani* has thus explained:

"In case an area sufficiently extended is shaken by a vibratory motion of internal origin and of an acoustic order, we will not have a true earthquake, neither such as our seismographes indicate nor such as we can determine an epicentrum from, but we will have a rumbling which can perhaps be indicated by a microphone properly placed".

Of very special interest, is the investigation carried out by *Alippi*, who was formerly professor of physics in the Royal Lyceum, Cosenza, Calabria [1]). His investigation has included a collection by communes of data upon the rumblings (he has used Van den *Broeck's* term, *mist-poeffers*); from which a noteworthy agreement of the reports is made out. The sounds are deep, begin feebly, are rapidly reinforced in intensity, and as rapidly die out. Sometimes they are audible at brief but irregular intervals almost continuously e day or night, and at other times only rarely. They have in this province been perceived (so far as investigated) only in or near the valley of the Crati and along the neighboring shore of the Tyrrhenian Sea; and in both zones they have appeared to come from the mountain masses of the Sila or Cocuzzo. *Alippi* has ascribed the rumblings to slips along the fracture planes of the upper and lower Crati as these have been determined by *Cortese.*

As we have shown in the following monograph there is evidence of the presence not of two fractures only, but of a net-work of dislocations in and about the Crati valley, and the explanation of Alippi does not adequately account for the mist-poeffers reported from the communes back from the margin of and within the Sila mass. *Alippi's* list of communes from which the mist-poeffers have been reported, to one familiar with the earthquake history of the district, reads like a report of damages after an earthquake in the province: since with hardly an exception the places included are those of evil reputation seismically speaking — communes which have again and again been racked by earthquakes. We have plotted *Alippi's* data upon the structural map (See Fig. 3 of the following article) and it at once appears that the mist-poeffers communes (also

[1]) *Tito Alippi,* I *mist-poeffers* calabresi. Boll. della Soc. Sismol. Ital. vol. 7, 1901—1902, pp. 9—22.

the seismic ones) are ranged in lines — the more prominent seismotectonic lines of the district and at the same time the striking lineaments upon the surface.

Since the appearance of *Alippi's* paper treating of the rumblings in and about the Crati valley, much has been learned regarding the distribution of such phenomena, and already a considerable literature has accumulated[1]) the titles in which indicate a wide range in the designation of this phenomenon by the Italian *contadini*. Besides extending the data concerning distribution, these studies show; first, that there is no sharp line of separation between the sounds which are heard at the time of earthquakes and the rumblings perceived at other times; and, second, that their distribution is clearly related to topography. In the words of *Alippi*:

"The rumblings . . . . . are produced in districts near to a mountain or to a chain of mountains or to lines of fracture. Thus the rumblings of the Tuscan Romagna seem to proceed from the slopes of the Appenines, or from Monte Falterona; those of Umbria and the Marche from the Appenines in general and more especially from Monte Nerone; the rumblings of lower Umbria are produced in the country situated also on the slopes of the Appenines (Spoleto, Narni, Terni) celebrated for its earthquakes (Morcia); the rumblings of the Val d'Orcia near Monte Amiata; the Calabrian rumblings . . . . . along a veritable seismic line. To this that I know it may be added that up to the present, at least, no one has reported Mist-poeffers in the great Paduan plain".

These rumblings seem likely to come into seismology under the name of *brontidi* (like thunder) a name suggested by *Alippi* in 1904.

The Central Office for Meteorology and Geodynamics at Rome has now taken up the matter, and the very satisfactory results of a

1) *A. Issel,* Considerazioni supplementari intorno al terremoto Umbro-Marchigiano del 18 Decembre 1897; Boll. della Soc. Seismol. Ital., vol. 5, 1899, pp. 59—71. *A. Cancani,* I rombi laziali del 6 Febraio 1900. Rendiconti della R. Acad. dei Lincei, classe di scienze fisiche, mat., e nat., vol. 9, 1900, pp. 304—309.

T. Alippi, I „*boniti*" del Monte Nerone. Boll. della Soc. Sismol. Ital., vol. 8. 1902, pp. 229—236.

T. Alippi, Les Boniti du Monte Nerone. Boll. Soc. Belge de Geol., vol. 17. 1903, translations and reproductions, pp. 69—75.

T. Alippi, Boniti e bombiti sull' alto Appennino Marchigiano, in relazione coi fenomeni sismici della regione. Boll della Soc. Seismol. Ital., vol. 9, 1903, pp. 99—114.

T. Alippi Il *baturlio della marina* nella campagna aretina e la *romba di Sassuolo* nelle campagne bolognesi e modenesi, ibid., vol. 10, 1904, pp. 1—8.

questionnaire sent to all correspondents in Italy are now being edited by *Alippi* and will soon be published. The suggestion of *Alippi* and *Cancani* that microphones might be utilized to determine with greater exactness the location of the sounds has not as yet been taken advantage of, but the map given indicates pretty clearly that there are some possibilities in this direction. Should the method be found practicable it would open a wide field for structural geological surveys, and give to acousto-tectonic lines an importance and interest equal to or even greater than seismotectonic lines.

To the writer it seems necessary to separate from *Cancani's* hypothesis of origin the idea of an epicentrum, and to explain the brontidi as caused by the slow settlement of orographic blocks and the consequent production of vibrations within their marginal zone — vibrations which have a low pitch and an intensity sufficient only to be heard by the unaided ear when in the immediate vicinity. *Alippi* has shown that the brontidi are more often heard when there are earthquakes in near-lying territory.

It seems likely that the sounds which have elsewhere been denominated *Barisal Guns*[1]), *mist-poeffers* (fog dissipators) etc. are to be explained in the same way. *Hughes* has described low rumblings often heard on the mountains north of the great Craven faults, and has explained them as due to the vibration caused at the time of formation of rock fissure-joints[2]). He believes such sounds not uncommon "along the lines of more rapid earth movement".

It is a fact of considerable interest that the sounds, which are clearly musical notes of pitch very near the lower limit of audibility, are produced in connection with the lighter earthquake shocks and especially the unfelt local ones. The after shocks of the great Indian earthquake of 1897 graded distinctly into rumblings. Out of observations made for a period of nearly a day (23 hours), 48 rumblings were heard only 7 of which were accompained by sensible shocks[3]). That the shocks were less common near the newly formed surface faults and especially the great Chedrang fault, seems to indicate that

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1) Report on "Barisal Guns" made at a meeting of the Sub-committee held on the 17th July, 1889, to consider the observations recorded during the year 1888. Proc. Asiatic Soc. Bengal, 1889, (1900), pp. 199—209.

2) *T. Mc.Kenny Hughes:* Curious aerial and subterranean sounds. Nature, vol. 53, 1895, pp. 30—31.

3) *R. D. Oldham,* Report on the great earthquake of 12th June, 1897. Mem. Geol. Surv. India, vol. 29, 1899, pp. 196—198

the adjustment is first obtained where the new faults are produced.

According to *Van den Broeck*[1]) sailors assert that the *mistpoeffers*, which are so common an occurrence along the coast of Normandy and Holland, are heard over the whole area of the shallow North Sea to Iceland. Water is so good a conductor of sound that this should be interpreted in the light of present knowledge as probably due to movement on fissure planes at the bottom of the sea. Of great significance is the three fold connection of brontidi, distant earthquakes, and the sudden flooding of mines by fire damp, apparently established by *Van den Broeck*[2]).

Chapter IV.

Dislocations at the earth's surface as the result of macroseisms.

The description by *Lyell* of a great surface fault 90 miles in length and with a throw of 9 feet, which occurred in 1855 during a great earthquake in New Zealand, has been often cited with some reserve though based on the independent reports of three individuals whose positions were such as to inspire confidence[3]). Since the publication of photographs of the great Neo Valley fault formed at the time of the Japanese earthquake of 1891[4]), there has been no lack of belief in such phenomena. It is probable that the number of such earthquake faults is larger than generally supposed, since no list of them has yet been published. It is therefore believed that the following compilation from original sources will be of value, both because it reveals the fact that actual ruptures of rock material at or near to the surface have accompanied nearly all macroseisms of the first order which have been carefully studied, and because the number is sufficiently large to permit of some generalization. The list makes no claim to completeness, but includes such examples as the author has encountered in his reading. Such surface fissures as might be traced to the action of earthquake waves upon the margins

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1) Nature, vol. 53, 1895, pp. 30—31.

2) *E. Van den Broeck,* Grisou et *mist-poeffers.*

3) *Sir Charles Lyell.* Principles of geology, 1868, vol. 2, pp. 82—89.

4) *B. Koto,* On the cause of the great earthquake of Central Japan, 1891, Journ. Coll. Sci. Tokyo, vol. 5, 1893, pl. XXXIV. See also, *J. Milne and W. K. Burton,* The great earthquake of Japan, 1891, pp. 1—10, pls. 29 and map.

of steep slopes of loosely consolidated material[1]) and those which arise in connection with the frequent land slips, have been excluded.

1783.

Calabria is the classical region for surface fracturing through earthquake shocks. In that rare and valuable work of the Naples Academy of Science[2]) these changes of relief have been well brought out. Near *S. Fili* and *Rosarno* clefts one half mile long, two and a half feet broad, and twenty-five feet deep were opened. In the vicinity of Plaizano three have been especially noted: one 1 mile long, 105 feet wide, and 30 feet deep; a second $^3/_4$ mile long, 150 feet broad and 100 feet deep; and a third $^1/_4$ mile long, thirty feet wide, and 225 feet deep. The throws upon these fissures ranged from 6 to 10 $^1/_2$ feet. Into the clefts near *Oppido* and *Polistena* houses and people with their live stock were precipitated and buried with the closing of the fissures[3]).

1789.

After the earthquake of 1789 an area of 60—70 square kilometers in the famous lake of Thingvalla in Iceland, sank between the fractures of Almangja and Hrafnagja from 2 to 3 meters[4]).

1811.

The great earthquake of New Madrid in the middle Mississippi basin produced the "sunk country", and hundreds of fissures, most of which ran in the direction NE-SW. When Sir. *Ch. Lyell* visited the district in 1846 they were still to be seen, some a half mile in length. The "sunk country" is 70—80 miles long and 30 miles broad[5]). Today are seen true fault scarps (one of 4 feet throw) which run E-W as well as NE-SW[6]).

1) See *T. Oldham,* Q. J. G. S., vol. 28, 1872, pp. 225—270.

2) *Sarconi,* Istoria di fenomeni del tremoto avvenuto nelle Calabrie e nel Valdemone nell' anno 1783, posta in luce dalla Reale Accademia delle Scienze e delle Belle Lettere di Napoli. pp. XIV and 351. Folio, with Atlas and 69 plates. Naples 1784. See also *Grimaldi,* Descrizione del Tremoto accaduto in Calabria nel 1783. Naples 1784.

3) *Sir Wm. Hamilton,* Account of the earthquakes which happened in Calabria, March 28, 1783. Phil. Trans., London 1783.

4) *F. de Montessus de Ballore,* Les tremblements de terre, Paris 1906, p. 110.

5) Principles of geology, vol. 2, 108.

6) *E. M. Shepard,* The New Madrid Earthquake, Jour. Geol. vol. 13, 1905, pp. 45—62.

1819.

At the time of the Indian earthquake of 1819 the *Allah Bund*, or Dam of God, was formed in a direction roughly parallel to the Rann of Cutch — the most striking feature of the country[1]. "Its steep slope rose like a wall above the plain, 16 miles in length. Geologists are not agreed as to the raising of the northern side of the fault, or the sinking of the southern one, but *R. D. Oldham* has shown that both movements have taken place and that the total displacement amounts to about 20 feet 6 inches."

1842.

In 1842 when *Sir Robert Sale* was besieged in Jalalabad by the Afghan army under Akbar Khan, a severe earthquake opened a breach in the entrenchments he had so laboriously raised[2].

1848.

The fault scarps produced in New Zealand during the earthquake of 1848 are according to *Gilbert* described by *Mc Kay*[3] and by *Hector*[4].

1855[5].

The earthquake which occurred in New Zealand January 23. 1855 produced a cleft near Wellington which was followed for 90 miles with a displacement of 9 feet[6]. The throw was measured by the displacement of a white band of nullipores as well as by the unweathered surface of the cleft. The fissure was open in many places.

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1) *F. de Montessus de Ballore,* The seismic phenomena of British India and their connection with its geology. Mem. Geol. Surv. India, vol. 35, 1904, pp. 1—42, 2 pls.

2) Ibid. p. 3.

3) *Alexander McKay,* On the Geology of the eastern part of Marlborough Provincial District. Colonial Mus. and Geol. Surv. New Zealand, Repts. Geol. Expl., 1895, pp. 129—133.

4) *James Hector,* ibid. p. XV.

5) Two heavy Californian earthquakes regarding which we have only meagre data are catalogued by Holden (Smith. Misc. Coll., no. 1087, 1898, pp. 35, 39). Of the quake of 1839 it is stated that, "One fissure extended from Lone Mountain? to the Mission San José". Of the earthquake of November 27—30, 1852 it is stated, "The shocks opened fissures at least 30 miles long in the Lockwood valley".

6) *Lyell,* Principles of geology, 1868, vol. 2, pp. 82—89.

1856.

In the fall of 1856 the earthquake in Tulare Country, California, was accompanied by the opening along the line of shock of a fissure in the earth's surface which is reported to have continued in a uniform direction for a distance of 200 miles[1]).

1857.

The great Californian earthquake of 1857 occurred at the time of the appearance of earth fissures, many of which are said to have opened on January 9. of that year. One at Fort Tejon was 20 feet wide and 40 miles long. "The sides then came together with such violence that a ridge was formed ten feet wide and several feet high." Another fissure appeared in the San Gabriel valley several miles long. The river left its bed and followed a new opening. A large fissure opened in the western part of San Bernardino. The current of Kern river was turned up stream. Many new springs appeared[2]).

1861.

The interesting earthquake of Aigion (Vostizza) in the Balkan peninsula, December 26. 1861 brought to light a series of three parallel and near-lying faults arranged *en échelon* along the base of a range of hills and extending between seven and eight miles. The several faults of the main series were connected by short cross faults. The plain of Achaja between the faults and the sea sunk bodily about two meters, the sea encroaching upon the land[3]).

1868.

The earthquake of August 15. 1868 in the province of Imbabura, Equador, which was an affair of a few seconds, was accompanied by the opening of a V shaped fissure 70 feet wide and 6 miles in length[4]).

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1) *E. S. Holden,* A catalogue of the earthquakes on the Pacific coast 1769—1897. Smith. Misc. Coll., No. 1087, 1898, pp. 1—253.

2) *Holden,* l. c.

3) Dr. *J. F. Julius Schmidt,* Studien über Erdbeben. Leipzig 1875, pp. 76—80, pl. 4.

4) *Edward Whymper,* Travels amongst the Great Andes of the Equator. 2nd ed. London, 1892, pp. 218, 219, 260, 267.

1869.

The fissures opened in the alluvial plain during the great earthquake of Cachar, which were regarded by *Oldham* as secondary phenomena due to the waves propagated from the seat of the disturbance [1]), *Suess* [2]) considers true displacements; and the plates of *Oldham's* paper clearly confirm this. *Suess* says:

"When the quaking was over, the alluvial ground was seen cut through by great clefts, which in many places by sinking of one side of the intersected land became true fault clefts and then appeared at the surface as low precipices only."

1872.

A fissure opened at the eastern base of the Sierra Nevada in connection with the Owens valley earthquake of 1872 upon which a throw of 20 feet was measured [3]).

"It occurred in 1872 and produced one of the most notable earthquakes ever recorded in the United States. The height of the scarp varies from five to twenty feet, and its length forty miles. Various tracts of land were sunk a number of feet below their previous positions, and one tract, several thousand acres in extent was not only lowered but carried bodily about fifteen feet northward. The ground was cracked in various directions and several springs permanently disappeared. . . . There was only one violent shock and the damage was all done in a few seconds".

In another place [4]) speaking of the same earthquake he says:

"Its origin was accompanied by the making of strips of land in such a way as to produce fault scarps identical in their general features with those described in the preceeding pages. The principal scarp follows the base of the alluvial foot slope of the Sierra Nevadas, and has a maximum height of about 20 feet. Where this height is attained, there is a companion fault scarp, ten feet high, facing in the opposite direction, so that the net displacement is about 10 feet. At other points the main scarp is associated with others running nearly parallel and facing in the same direction".

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1) *R. D. Oldham,* Mem. Geol. Surv. Ind., vol. 19, 1882, pp. 1—98 map.

2) *Ed. Suess,* Antlitz der Erde, vol. 1, 1885, pp. 67—68.

3) *G. K. Gilbert,* A theory of the earthquakes of the Great Basin with a practical application. Am. Journ. Sci., 3rd. ser., vol. 27, 1884, pp. 49—53.

4) Lake Bonneville, Mon. I, U. S. Geol. Surv., 1890, p. 361.

A neighbouring earthquake fault produced at the same time has been described by *Whitney*[1]). A fissure was opened in the earth from about two miles south of Lone Pine extending ten miles farther north. It was four feet wide and the ground on the east side sunk four to twelve feet lower than that on the west.

1875.

After the heavy shocks of February, 1875 the depression of Sveinagjá, 15 kilometers in length and 400 to 500 in breadth, located about 25 kilometers to the eastward of Myvatu in Iceland, deepened between its bounding faults by an amount varying from 15 to 20 meters[2]).

1884.

On October 4th. 1884, three trans-Atlantic cables were interrupted simultaneously at the base of the steep eastern slope of the continental shelf (The Flemish Cap) 330 miles from St. Johns, New Brunswick. The cables here run in parallel lines about ten miles apart, and the ruptured places fell opposite each other in a straight ine[3]). Of these breaks *Milne* says:

"Such a change does not necessitate any alteration in depth such as could be detected by sounding, but either a landslip along a line of considerable length or simply a line of fracture like that which was suddenly formed along the Neo Valley in Japan in 1891".

1886.

In connection with eruptions on June 14, 1886, in the Tarawara range of volcanoes in New Zealand, one large fissure and a number of smaller ones opened in a direction parallel to the line of volcanoes. The main cleft was about 6 miles long and ran in a nearly straight direction, N. E. — S. W.[4]).

"It is a very noticeable fact that all of the cracks we saw took the general northeasterly direction of the line of volcanic action, and

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1) *J. D. Whitney,* The Owens Valley earthquake of March 26, 1872, Overland Monthly, vol. 9, 1872, p. 273. Quoted by *Holden,* l. c. p. 92.

2) *F. de Montessus de Ballore,* Les tremblements de terre, Paris, 1906, p. 110.

3) *John Milne,* Sub-oceanic changes. The Geographical Journal, London, vol. 10, 1897, p. 262.

4) *James Hector,* Presidential address before the Wellington Philosophical Society, Trans. and Proc. New Zealand Inst., vol. 19, 1886, pp. 461—470, map in text. See also *Pond* and *Smith,* ibid., p. 353.

all of them, followed closely along depressions in the surface, which are undoubtedly old cracks due to much heavier earthquakes in the past".

1887.

The Sonora earthquake of May 3rd., 1887 in the southwestern part of the United States and in Mexico was clearly the result of faulting[1]). One cleft which was formed maintained a zigzag course in the direction from north to south for more than 35 miles, and had many lateral fissures. When the direction of the main fault changed, a fissure at the elbow extended the former direction. The maximum throws ranged from 8 to more than 20 feet. Nearly every river bed within the affected district changed its level as a result of independent displacements by amounts varying from 6 inches to two feet. In addition there were found many fissures without noticable displacement.

Another account of this earthquake has been given by two geologists who happened to be at the time upon the borders of the region affected[2]). In the Sulphur Spring Valley east of Bisbee, Arizona, they found "great numbers of cracks and dislocations. For distances of several hundred feet along some lines with a generally north and fouth course, vertical downthrows on one side of from one foot to two seet and more were seen, the depressed portion rising either gradually or by a vertical step to the original level". The direction of the shocks in this vicinity was from north to south.

The work of Goodfellow in connection with this earthquake was undertaken at the request of *Maj. Dutton*, who has recently supplemented the data. He says[3]):

"Another fact which is suggestive was the occurrence of another fault formed at the same time on the opposite or eastern side of the Tevas range with its throw in the opposite direction. In other words the range seemed to have been uplifted several feet between faults on either flank".

1887.

The great earthquake of June 9th. 1887 at Verny in the Cau-

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1) *George E. Goodfellow,* The Sonora earthquake, Science, vol. 11, 1888, pp. 162—166.

2) *T. Sterry Hunt* und *J. Douglas,* The Sonora earthquake of May 3rd. 1887. Trans. Seismol. Soc. Japan, vol. 12, 1888, pp. 29—31.

3) *C. E. Dutton,* Earthquakes in the light of the new seismology, London, 1904, pp. 53—56.

casus produced faults of considerable magnitude along some of the smaller river valleys of the district. The numerous large landslips which in districts of sharp relief and lightly consolidated material are the accompaniment of all great earthquakes, tend to conceal them; but their description as faults by *Mouchketow*[1]) is justified by certain of the photographs reproduced.

Chapter V.

Dislocations at the earth's surface produced at the time of macroseisms-Concluded.

1888.

During earthquakes in the Amuri District, New Zealand, in the months of September and October, 1888, fissures opened in the Wayau — ua and Hope valleys, on one of which fractures fences were shifted laterally $8^1/_2$ feet.

"All these rents and fractures lie along a line of previous earthquake disturbance, the old fractures indicating this being traceable on the surface when the line does not run along river beds"[2]).

1891.

The Neo Valley fault produced at the time of the Mino-Owari earthquake of 1891 was followed for a distance of 40 miles[3]) and had throws of more than 10 meters[4]). Of this fault *Kotô* says:

"In my opinion it can be confidently asserted that the sudden formation of the great fault of Neo was the actual cause of the great earthquake of the 28th. of October 1891, which shook an area comprising 243.055 square kilometers or more than 65 °/o of the whole extent of the Empire of Japan".

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[1]) *J. V. Mouchketow,* The earthquake of Verny, May 28th (June 9th) 1887. Mem. du Comité Geol., vol. 10, Nr. 1, 1890, pp. 1—154, 4 maps and 43 text figures (in Russian).

[2]) *Alexander Mc. Kay,* Remarks on earthquakes in the Amuri District, South Island. Trans. and Proc. New. Zealand Inst., vol. 2, 1888, pp. 508—509.

[3]) *Dutton,* gives 70 miles or almost across the island (l. c. p. 56) and de Montessus 110 miles (l. c. p. 416).

[4]) *B. Kotô,* On the cause of the great earthquake of Central Japan, 1891, Journ. Coll. Sci. Univ. Tokyo, vol. 5, 1893, pp. 295—353, pls. 28—35.

Also *J. Milne* and *W. K. Burton,* The great earthquake of Japan, 1891, pp. 1—10, pls. 39 and map.

In addition to the main fault there were produced many small faults and fissures. Over the fissures in the looser material there was often formed a series of irregular parallel cracks and elevations resembling, though on a larger scale, the track of a mole beneath the surface. So common are such phenomena in connection with the Japanese earthquakes that there has grown up a popular superstition that a giant catfish moves below the surface at the time of earthquakes.

1892.

In some respects the most valuable field observation yet recorded in connection with an earthquake is concealed in a narrative of geographical exploration by an army officer. Both because of the great interest of the locality, and the thoroughness of the examination, the description is here quoted in full[1]).

"Before going farther, I must say a few words about a very curious physical feature in this neighborhood which may be of interest to you. To explain it I must refer to a severe earthquake shock which on December 20, 1892, was felt over a large area of Beluchistan, during which the railway line between *Quetta* and *Chaman*, at a place near the *Chaman* end of the great Khojak tunnel, but fortunately outside that tunnel, was very curiously damaged. The rails were distorted, and to put the matter briefly, the distance between *Chaman* and *Quetta*, was lessened by no less than 2 1/2 feet. A fissure in the ground was found to run across the railway line at this place, and this fissure, running along a depression in the ground along the foot of the Khwaja Amran range, was then traced to a short distance on either side of the railway line.

It so happened that when our boundary work made us more carefully examine this country, we found that a well marked line of depression or indentation in the ground was traceable near the edge of the plain near *Murghachaman*, some 18 miles north of *Chaman*. Following this line, or as I may call it this earthquake crack, we found it to run some 18 miles in a well-defined line to the very place where the earthquake fissure had damaged the railway line in

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1) *Capt. A. H. Mc. Mahon,* The Southern border lands of Afghanistan. The Geographical Journal, London, vol. 9, 1897, pp. 402—403. See also Davison, Note on the Quetta earthquake of December 20th, 1892, Geol. Mag., Dec. III, vol. 10, 1893, pp. 356—360, sketch map.

1892. Thence it ran on, gradually ascending diagonally the slopes of the Khwaja Amran range until it actually cut the crest of the main range near its highest peak. Descending again into the Spentizha valley, it began again to ascend diagonally the slopes of a continuation of the Khwaja Amran range. Cutting this range in a similar manner, it descended to the Lora river, and crossing that river, ran along the whole length of the foot of the Sarlet range to Nushki. Bayond this point we were unable to follow it. The total length of this wonderful earthquake crack, which we carefully surveyed, was no less than 120 miles. It is a well-defined broad line of deep indentation in places as clearly defined as a deep railway cutting. Along the whole course of it are to be found springs of water, cropping up here and there. Both from the presence of water and from its forming a short cut across mountain spurs, this crack is largely used as a thoroughfare. We found that the old greybeards of the tribes residing in the neighborhood all knew of its existence. They told us that during their lifetime, on some three occasions after severe earthquake shocks, deep fissures had appeared along this line, and that they had similar accounts handed down to them by their fathers. After one of these occurrences, the water-supply of the springs along the crack had, they said, largely increased . . . . This crack seems to mark the line ot a gigantic geological fault. All the rocks on the east appear to be sedimentary while those on the west appear to be igneous. In fact, as far as the Persian border to the west of it, we found nothing but igneous rocks".

1894.

The earthquake of Shonai, Japan, in 1894 was accompanied by the opening of a cleft known as the Yadare-Sawa cleft, which ran some 30 kilometers in a direction Nr. 55^0 E[1]).

1894.

During the earthquake shocks near Locri, Grece, in the month of April, 1894, a fissure 35 kilometers in length and having a maximum throw of one and one half meters, opened parallel to the shore of the Bay of Scroponeri[2]).

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1) *B. Kotô,* Geological researches upon the earthquake of Shonaï. Report of the Earthquake Committee, vol. 8, Tokyo, 1896, (in Japanese). Referred to by Yamasaki in Pet. Mitt., vol. 46, 1900, pp. 249—255.

2) *Socrati-A. Papavasiliou.* Sur les tremblements de terre de Locride (Grèce) du mois d'Avril, 1894 (presented by *F. Tisserand*). C. R. de l'Acad. Paris vol. 119, 1894, pp. 112—114.

"But the most remarkable phenomenon was the formation of a great crevice 55 kilometers in length (in the plan) and some centimeters to 3 meters in width according to the nature of the ground (width was in general not great), which was followed in the constant direction of the Bay of Scroponeri as far as the city of Atalante, which it traversed to the end; thence it followed a direction always from southeast to northwest, but gently sinuous, and was lost near the village of Saint-Constantine".

1896.

During the month of August, 1896, powerful earthquake shocks occurred within an area in southwest Iceland. Before, during, and after the shocks the great neighboring active volcanoes remained quiet. In some respects these surface dislocations take first rank in interest of any that have been described[1]).

"A great many clefts were formed in the land areas Ranjárvellir, Land and Skeid, and many of them had great dimensions. An open cleft clear across Skeid from NE to SW was 12 kilometers, another in Land with direction N 10° W was 15 kilometers in length, and was accompanied by many parallel clefts. Along several of these clefts great funnel-shaped holes were formed". These were apparently the "craterlets" of some other earthquake descriptions.

Of very especial interest is *Thoroddsen's* observation that the great shocks of August 26., August 27., September 5., September 6. and September 10.; were each localized within polygonal areas bounded by dislocations, indicating that these earth blocks were moved bodily as units, though doubtless also with internal adjustments. This is set forth with great clearness upon *Thoroddsen's* map.

1896.

In connection with the earthquake of Northern Honshu, Japan, which occured on the 31. of August, 1896, two long lines of dislocation appeared. These clefts, the Kawafuna and Senya clefts, were located on opposite side of a mountain mass, and were, the one 15 and the other 16 kilometers in length. Along these dislocations the land upon one side sank between two and three meters[2]). These

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1) *Dr. Th. Thoroddsen,* Jardskjálftar á Sudarlandi (in Icelandic), Copenhagen, 1899, pp. 200. Brief outline published under title, Das Erdbeben in Island im Jahre 1896, Pet. Mitt., vol. 47, 1901, pp. 53—56, 2 maps.

2) *Dr. U. Yamasaki,* Das grosse japanische Erdbeben im nördlichen Honschu am 31. August, 1896. Pet. Mitt., vol. 46, 1900, pp. 249—255, map.

true fault planes maintained their courses across all kinds of rock, and over plain, hill, and valley without deviation. Their bends are relatively sharp and amount to 10°—20°. Beyond where they are visible as dislocations their course may still be followed in lines of destroyed villages.

1897.

The earthquake of western Assam and eastern Bengal on June 12. 1897 was perhaps the greatest in history[1]). One of the most noteworthy features of *Oldham's* map consists in the number of rectilinear boundaries of the several destructive areas. The southern boundary of the area characterized by the heaviest shocks is a nearly straight line directed west northwest and extending a distance of 350 kilometers. Several large faults appeared at the surface of the ground; one, the Chedrang Fault, was 20 kilometers in length with a measured throw in places of 10 meters. From these larger faults lesser ones branched. Others which did not appear at the surface as faults brought about changes of level so as to form lakes, of which no less than thirty are recorded (one 2·5 kilometers across). The shocks were always greatest in the vicinity of the fault planes. The area in which faults were observed was about 300 miles by 400.

It is certain that the figure given does not represent the total number of faults formed at the surface during this earthquake, since the area examined was but a small part of that effected by the disturbance.

1898.

The earthquake of Sinj in Austria which occurred in 1898, was accompanied by the appearance of small but definite step faults at the surface of the ground[2]).

1899.

Tarr and *Martin* have recently announced an important result of the earthquake shocks of September, 1899 in Alaska[3]).

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[1]) *R. D. Oldham,* Report on the great earthquake of 12th. June, 1897. Mem. Geol. Surv. India, vol. 29, 1899, pp. xxx and 379, 44 pls. 3 maps, and 51 woodcuts.

[2]) *A. Faidiga,* Das Erdbeben von Sinj am 2. Juli, 1898. Mitt. d. Erdbeben-Kom. d. k. k. Akad. d. Wiss. z. Wien, N. F, Nr. 17, 1903, pp. 23—25.

[3]) *Ralph, S. Tarr, and Lawrence Martin,* Recent changes of level in the Yakutat Bay region, Alaska. Author's abstract of paper to be presented at

"During the earthquake shocks of September 1899, which was felt along a part of the Alaskan coast, the Yakutat Bay region was the seat of marked disturbance accompanied by decided changes of level along the shores of the bay, amounting on one part of the coast to an uplift of 47 feet. The change of level was differential, indicating a complex system of faulting on a large scale; and shattering of the rocks proves much differential movement on a smaller scale."

1902.

During the great earthquake of Chemakha, Turkestan, which occurred February 13, 1902, trough-like depressions were produced by the opening of fissures on opposite sides of valleys, the cracks running sometimes straight and at other times in zigzags, and crossing the minor variations in relief without deviation of their courses. From the fissures thus produced enormous quantities of salty plastic mud exuded, and subsequent shocks fractured the flat mounds of this mud so as to form sharply defined scarps on essentially vertical planes with displacements amounting in some instances to 1 1/2 meters[1]).

1906.

The earthquake of January 10, 1906 at Tokaj in Hungary accompanied the formation of distinct surface faults[2]).

1906.

The great California earthquake of April 18, 1906 was accompanied by movements of earth blocks both vertically and laterally, the movement being greatest along two lines extending northwesterly one, at least a nearly vertical fault. Lateral translations of as much as 3 meters, and vertical throws of as much as 6 meters were measured[3]). All the farms, roads, rivers, walls and water pipes, have been shifted

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the eighteenth winter meeting of the Geological Society of America, December 27—29, 1905.

1) *V. Weber,* The earthquake of Chemakha of January 31 (February 13), 1902. With two pls. and a map. Mem. du Comité Géol., N. S., Nr. 9, 1903 (in Russian).

2) The report upon this earthquake is published in the Hungarian language and the author is indebted to Herr *Rethly* of the earthquake station of Budapest for a German translation and a series of photographs.

3) *A. de Lapparent,* Le tremblement de terre de la Californie, d'aprés le rapport préliminaire officiel. C. R. d. Sc. Paris, vol. 143, July 2, 1906, pp. 18—20.

and thrown on one of these planes, and the maximum of distruction is localized upon them.

The above list could certainly be much extended if scientific observations had been long and regularly made in such well known earthquake regions as the Western United States, and in fact throughout the Cordilleran mountain system. *Gilbert*[1]), *Russell*[2]), and others have drawn attention to the evidence for considerable movements on numerous fault scarps within the area of the western United States. Some of these are so recent that living trees have been disturbed and vegetation has not started upon the ruptured surfaces. As the region is one of violent earthquakes the connection of the two phenomena hardly admits of doubt.

Great fissures called *quebradas*, which are recognised to be earthquake cracks, are among the most common features in the Andes near the equator. Speaking of Cotocachi, *Whymper*[3]) says:

"The lower slopes of the mountain, and the comparatively flat ground at its base, were rent and riven in a most extreme manner. In no other part of Equador is there anything equalling this extraordinary assemblage of fissures, intersecting one another irregularly and forming a perfect maze of impassible clefts . . . . . . The cracks are all V shaped, and though seldom of great breadth are often very profound, and by general consent they are all *earthquake quebradas*. Several, at least have been formed within the memory of man, while others are believed to be centuries old."

The great ravine of Guallabamba 2000 feet in depth, forms the boundary of a mountain mass 14.000 feet in height and covering a vast territory.

"While for the most part its slopes are not steep, the abruptness of its cliffs bordering the quebrada can hardly be exceeded; and there is nothing elsewhere in the neighborhood of equatorial America equaling the grandeur of this profound earthquake fissure."

The fissures formed at Riombamba in the same region at the time

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1) *G. K. Gilbert,* Lake Bonneville, p. 361. Also, Fault Scarps, Comptes Rendus Congr. Géol. Intern., 5 me. Ses., Washington 1893, p. 376. Also, A Rock Fissure, Science, N. S., vol. 2, 1895, pp. 117—119.

2) *I. C. Russell,* A Geological reconnaissance in southern Oregon, Fourth Ann. Rept. U. S. Geol. Surv., 1884, pp. 436.

3) *Edward Whymper,* l. c., p. 260.

of the earthquake of February 4, 1797, are well known from *von Humboldt's* description [1]).

In earthquake-racked New Zealand similar conditions have been interpreted in much the same way [2]).

"In the northern part of the South Island, and indeed throughout the islands of New Zealand, there are many old faults, showing a great vertical displacement running coincident with earthquake rents opened but recently, though not for the first time".

Deckert states that from the Mexican earthquake district special reports are available concerning between 30 and 40 catastrophic earthquakes, all of which had intensities measured as X in the Rossi-Forel scale [3]).

A survey of the above list seems to warrant the following generalizations concerning surface dislocations at the time of earthquakes:

1. *Appreciable surface dislocations appear to be formed only at the time of macroseisms, and the throws upon these planes stand in some relation to the magnitude of the disturbance.* There is in this nothing surprising if the origin of the shocks be traced to the displacement. The maximum vertical displacement so far fully described on a fault of this character is about 33 feet [4]) (Neo Valley in 1891 and India in 1897). Values nearly as great were reported from India in connection with the earthquake of 1818 (20 ft 6 in.), Owens Valley in 1872 (20 ft.), and Sonora in 1887 (20 ft).

2. *The evident dislocations produced are generally of two orders of magnitude, those of the higher order being very limited in number, while those of the lower order are often quite numerous.* The highest number of major faults reported in connection with any earthquake is three (India 1897). In the case of the earthquakes of Owens Valley

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1) *Cosmos,* vol. 4.

2) *Alexander Mc. Kay,* Earthquakes in the Amuri District, South Island. Trans. and Proc. New Zealand Inst., vol. 21, 1888, p. 509.

3) *Emil Deckert,* Die Erdbebenherde und Schüttergebiete von Nordamerika in ihren Beziehungen zu den morphologischen Verhältnissen. Zeitschr. Gesellsch. f. Erdkunde zu Berlin, 1902, p. 372.

4) This foremost position should perhaps be taken by the earthquake of Iceland, 1875, of which it is stated (See p. 241) that the depression of Sveinagjá sank between faults 15 to 20 meters; but the data given are so brief that it is thought sufficient to note the fact here. Since this paper was written the author has been permitted to see the proof of the paper by *Tarr* and *Martin* above referred to in which a fault of 47 feet is proven to have originated in 1899.

(1872), Sonora (1887), and Honshu (1896], the number was two[1]); whereas in all other instances a single though often zigzaging dislocation has been described. In Owens Valley (1872), Sonora (1887), Mino-Owari (1891), Honshu (1896), and India (1897) the number of subordinate faults and fissures was very considerable. The surface displacements upon these minor faults in the Indian quake was probably in the larger number of cases to be measured in inches rather than in feet; and these were quite as often indicated by the formation of lakes or other modifications of drainage as in visible cracks, though the latter were numerous.

This rather sharp differentiation of major and minor faults in connection with earthquakes accords well with the view of Milne that the larger displacements are formed along new fissure planes and the others are due to adjustment along old fractures[2]):

"Nearly all large earthquakes are followed by a long series of aftershocks. These, which are most frequent in the epifocal area, are regarded as sudden settlements and adjustments on the fault plane or planes created at the time of the primary disturbance.

. . . Microseisms may for the most part be regarded as settlements along lines of fissures and amongst disjointed materials, the first formation of which was in all probability macroseismic[3]) in character. Some, no doubt, are initial stages in primary fissuring; but the majority, when traced to their birthplace, find an explanation in some slight shift on the line of an existing fault".

As regards the macroseisms it is natural to assume that had fissure planes existed along the line of subsequent faulting, relief would have been found before the stresses had accumulated for so grand a disturbance.

3. Earthquake dislocations are normal faults with hades approaching the vertical. The evidence is here all of one kind, dislocations of the thrust type being as little warranted by the observations as would be their formation *in surface layers* by the modern conception of crustal deformation. It is somewhat surprising that the "Ridgeway Fault" should have been chosen by the Seismological Committee of the

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1) Probably more in Owens Valley and Sonora.

2) l. c. p. 21.

3) The use of this term is the one which the writer has adopted, but the reciprocal interpretation is also in vogue, and the word is used in this sense by Professor *Suess* (63) in the introduction.

British Association[1]) for the measurement of earth movements. This "fault" is well understood to be a thrust of very flat hade, and it is, therefore, in no way surprising that the results should have been negative.

4. A considerable lateral shift along the larger planes of dislocation has sometimes been observed, and is probable in other instances. The lateral shift along the great Neo fault was as much as 13 feet, a shift of 15 feet is recorded along the Owens Valley fault and 8 feet 6 inches on a fault in New Zealand in 1888. Triangulation surveys made after the Sumatra earthquake of 1892, the Indian earthquake of 1897, and the Saloniki earthquake of 1902 reveal also a lateral shifting of the stations.

5. The crustal movements indicated at the surface at the time of earthquakes appear to be due to an adjustment in position of individual blocks. Such movements appear to allow of treatment: first, as they concern relatively large masses along large displacements: and second, as regards minor adjustments within the larger units. The movements attending the earthquakes of Sonora (1897) and Honshu (1896), have much in common. In each instance a considerable mountain mass bounded by newly formed displacements on opposite sides, underwent a bodily movement relatively upward with regard to the country upon either side. Without the postulation of a flow of rock material near the earth's surface — and such an assumption is excluded — it is necessary to suppose that displacements occurred at the ends as well as the sides of these orographic blocks. These being distributed over the numerous secondary fissures were less apparent though many were found. Similar assumptions are necessary to explain the sudden mass movement of such large tracks of country as were shifted in connection with the Owens Valley (1872) and Indian (1897) earthquakes, and others.

The two main faults of the Owens Valley disturbance, like those of Sonora and Honshu, were nearly parallel, and the throws were relatively downward outside the included block. *Gilbert* speaks of the mass movements of the country as taking place in strips; hence the movement must have been similar to that produced during a readjustment of the blocks within a mosaic. The expression *marqueterie*

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1) *Clement Reid,* Selection of a fault and locality suitable for observations on earth movements. Rept. Brit. Ass. Adv. Sci., 1900, pp. 108—118. See also, Horace Darwin, ibid., pp. 119—120.

used by de Lapparent for the structure of dislocated areas of crust is even better adapted to such conditions.

Chapter VI.

Seismic methods for locating fracture systems.

If it were suggested that the new methods which are to be discussed should apply to the location of fractures, rather than fracture systems; the reply would be that the formation of a single fracture plane within the earth's crust unrelated to other fractures, is believed to be a phenomenon no less rare than the development of an anticline or syncline not a component part of a system of flexures. Such, at least, seems to be the teaching of mechanics, supported by experimentation upon the failure of elastic bodies like glass under both tensional and compressive stresses. Such a system of fractures as is called for by theoretical and experimental considerations has, however, but seldom been proven to exist on a large scale in nature; whereas unique fractures are among the commonest features of geologic maps. An adequate explanation of this apparent divergence of observation and theory might well be found in the difficulty with which the presence of faults is proven, covered as they so generally are by superficial deposits. The only method generally accepted for proving that a dislocation has occurred upon a plane of fracture, is the discovery of a bed whose identity can be established, which has its two parts actually separated on that plane. There are, however, other methods by which the great probability of a fault may be indicated, and these were stated by the writer in 1901 [1]). The caution displayed in not asserting the presence of a fault not absolutely known is in itself commendable; but in studies upon folded districts the unconscious error has too often been committed of assuming that the present abnormal positions and attitudes of rock beds are wholly the result of folding, *because this is a possible explanation and one which forces itself upon the attention.* In picturing the geologic structure of a region the error of neglecting the unknown — because undiscovered — element may be not less, but rather greater, than that of bringing into account fractures not absolutely proven, though indicated as probable by a series of correspondences.

1) The Newark System of the Pomperaug Valley, l. c.

The supplementary methods by which the presence of fractures may be inferred, are both geologic and topographic, and may be said to have as their common characteristic the rectilinear in contrast to the curvilinear element as they are projected upon maps. To such elements the name *lineament* has been applied, and it will be understood from what has already been said that their recognition is based less upon the properties possessed by each individually than upon its constituting an element within a system which has regional characteristics as regards orientation especially [1]).

If the faults of a district be difficult of determination, the joints are correspondingly easy to find; and much has been learned through a study of the orientation of joint systems. The indication from the study of lineaments is that they are grouped within networks similar to and oriented like those of joints, from which as systems they differ in common with faults by the grander scale of their ground plan. Thus in inferring the presence of faults where the cover and the lack of sufficient dissection of the crust makes their absolute identification impossible, the worker is guided not only by observing the rectilinear elements in geologic boundaries, in fall lines, in cliff faces, in sea bluffs, in rias coasts, etc.; but by noting the relation which these bear to each other (as regards parallellism) and to the observed joint system of the district (as regards orientation).

An objection has been made to the location of lines of dislocation through the mapping of scarps, even where these are admitted to have been originally formed through faulting of the crust; on the ground that the processes of degradation must by sapping give a lateral shift to the cliff. As regards the actual position upon the ground considerable shifts from this cause may be granted, but measured in values of the same order as the height of the scarp.

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1) The river system of Connecticut. Jour. Geol., vol. 9, 1901, pp. 469—484, pl. 1. The mapping of the crystalline schists, ibid. vol. 10, 1902, pp. 858—890. Lineaments of the Atlantic border region. Bull. Geol. Soc. Am., vol. 15, 1904, pp. 483—506, pls. 45—47. (Abstr. Intern. Geogr. Cong., St. Louis, 1904, pp. 193—203). Tectonic geography of southwestern New England and southeastern New York. Bull. Geol. Soc. Am., vol. 15, 1904, pp. 554—556. The tectonic geography of Eastern Asia, Am. Geol., vol. 34, 1904, pp. 69—80, 141—151, 214—226, 283—291, 371—378. Examples of joint-controlled drainage from Wisconsin and New York. Jour. Geol., vol. 13, 1905, pp. 363—374. The correlation of fracture systems and the evidences for planetary dislocations within the earth's crust. Trans. Wis. Acad. Sci. etc., vol. 15, 1905, pp. 15—29.

Upon the scale of the maps, it is however, not likely that appreciable changes either in position or in direction of lineaments arise from this cause. To the wandering of the cliff from the position of the fault plane to which it is causally related, an effective counter influence is exercised by erosion as it encounters the alternating layers of varying hardness. This will be clear from Fig. 1. In the second diagram of the figure a dislocation is shown to have occurred, erosion having gone on meanwhile. The third diagram shows a wandering of the cliff from the fault line in consequence of sapping. In the fourth diagram a new cliff has formed near the fault and has begun to wander in the direction of the downthrown limb, since the harder layer is now uppermost there. Essentially similar conditions, will alternately develop a topographic break on opposite sides of but near to the fault as degradation progresses.

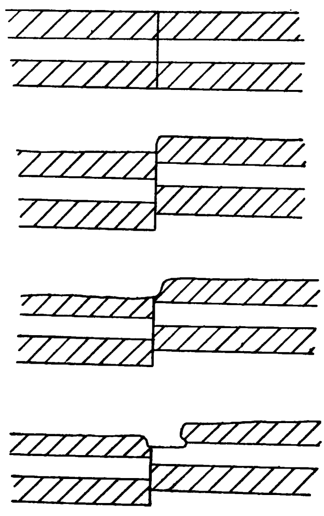

Fig. 1.

Diagrams to illustrate the effect of alternate layers of varying hardness upon the position of a fault cliff in progressive stages of degradation.

There seems to be a rather general belief that a cliff may be traced to a fault only when the surface of the ground is higher upon the upthrown side. While this is doubtless always the case when the movement along the fault has been comparatively recent, the reverse is quite as likely to be true of ancient dislocations, as has been indicated by the diagrams. It has been shown that within the complexly faulted district of the Pomperaug Valley, Connecticut, in which the principal movements occurred in post-Newark and pre-Cretaceous time, the downthrown blocks are almost universally the prominent projections upon the surface, owing to the fact that a hard layer of basalt is in them near the present erosion level.

The studies upon Calabrian earthquakes have supplied a new and very sensitive method for locating the position of fault planes through the surface distribution of seismic intensity. The seismotectonic lines derived from this study connect places where shocks were heaviest and not only show the position of the plane of dislo-

cation but represent the trunk lines along which earthquake waves travel with least loss of intensity. Their intersections have additionnal importance because successive shocks arrive at them from different directions; and they combine to produce rotatory effects particularly disastrous to structures. Such movements, which are well illustrated by the rotated monument figured so often from the report upon the Calabrian earthquake of 1783, have been particularly often felt in Calabrian communes which have the first order of seismic importance.

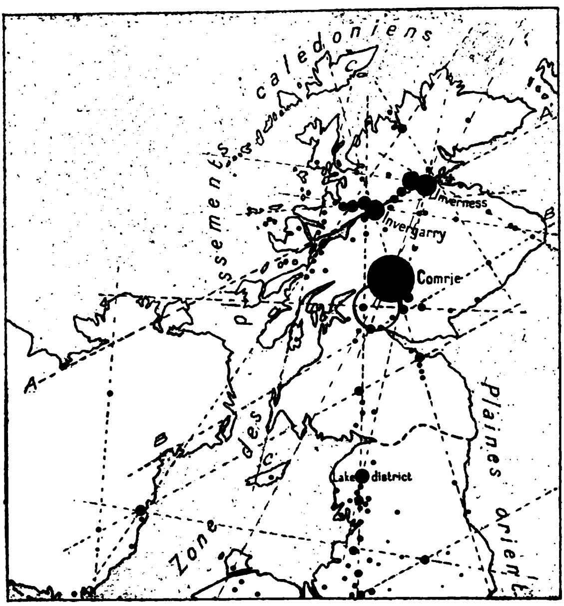

Fig. 2.

Seismotectonic map of Scotland, northern England, and northeastern Ireland (Seismic data after de Montessus).

One of the strongest supports for the view that seismotectonic lines are identical with fault planes, is their coincidence with important lineaments. In the preceding chapter it has been indicated that a similar method of study may be applied to the acoustic phenomena arising from the slower earth movements, or Bradyseisms, which go on between successive periods of earthquake disturbance.

The completion of de Montessus's statistical compilation furnishes us with further material to which these methods may be applied; for upon a far grander scale his studies reveal the surface distribution of seismic intensity. For studies upon this scale, as already pointed out, the conception of the epicentrum, however wrong in principle, is well adapted; since it generally gives the approximate geographic center of the district affected by an earthquake. As will be shown below, however, it is far better adapted to seismic disturbances of small extent.

So observe the manner in which the seismic maps of de Mon-

tessus reveal the structural lines, it will be necessary to reproduce some of them. Fig. 2 is reproduced from a portion of his map of the British Isles, the seismotectonic lines only being added[1]). These, it will be noted, are in nearly all cases important lineaments; among which the series directed east-north east is most prominent and at least three coincide with known faults (AA′, BB′, CC′). A series directed N—N 5° E., another N 15° E, and a third a little to the north of west (average about N 80° W); are also clearly indicated. The positions of greatest prominence as regards seismicity are, just as in the Calabrian province, the intersections of seismotectonic lines. Upon de Montessus's map the prominent Comrie locality has been displaced northward evidently in order to show the epicenters in its vicinity. Its corrected location offers no exception to the law elsewhere conformed to.

Equally striking is the seismic map of the greater Antilles (Fig. 3). Here by far the most prominent seismotectonic line

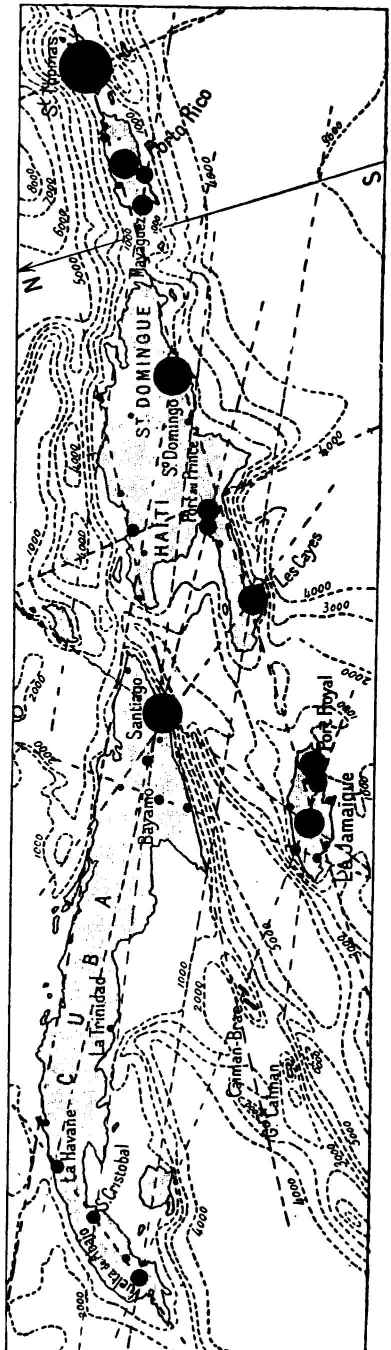

Fig. 3. Seismotectonic map of the Greater Antilles (Seismic data after de Montessus).

1) See a larger scale map in de Montessus, Relations géologiques des régions stables et instables du nord-ouest de l'Europe. Ann. de la soc. scient. de Bruxelles. vol. 27, 1903, pl. 2, pp. 1–48, pl.

runs from Jamaica to St. Thomas following the southern coast line of Hayti and San Domingo and the northern coast line of Porto Rico. A nearly parallel line follows the south eastern coast of Cuba and the northwestern coast of Hayti. Other lines are only less clearly brought out, and all are prominent lineaments. Among them three distinct series are clearly indicated (N. 75° E., N. 80° W. and N. 25° W.). The localities of high seismicity fall with much precision at the intersections of seismotectonic lines[1]).

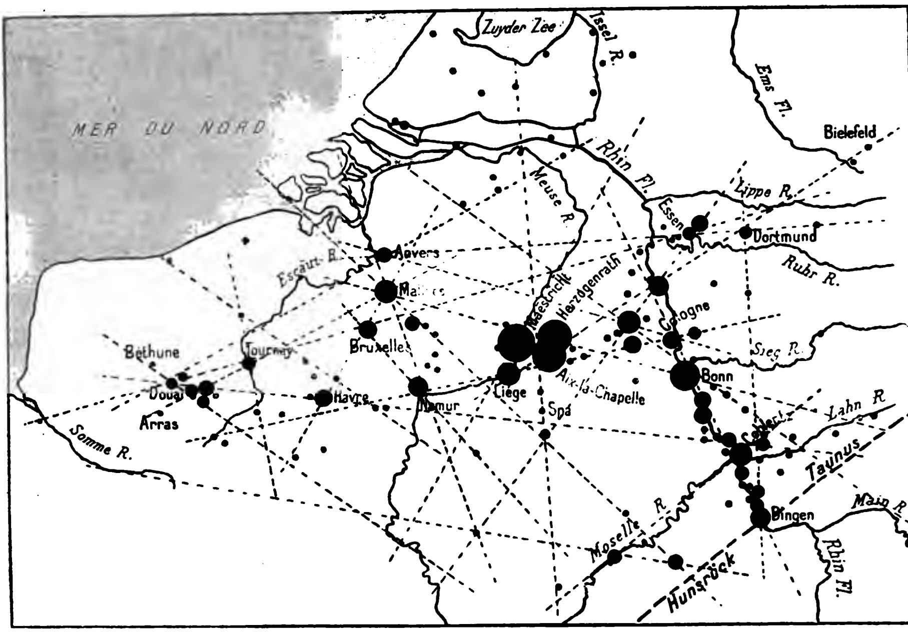

Fig. 4.

Seismotectonic map of portions of France, Belgium, and Germany (Seismic data after de Montessus).

Other illustrations of a like nature have been selected almost at random from the more than four score maps prepared by de Montessus. Fig. 4 shows the Rhine valley from Cologne to the bend at Bingen marked out strongly. As is well known, this area is intersected by a network of faults having many series, and it is

[1]) Cf. De Montessus, Les relations sismico-géologiques de la méditerranée antillenne. Memorias de la Sociedad cientifica „*Antonio Alzate*", Mexico, vol. 19, 1902—1903, pp. 351—373, pl. 11.

interesting to note how largely the recent movements have been localized upon the series of planes on which the crust was depressed in order to form the valley floor.

In Fig. 5, the seismotectonic map of Switzerland, the correspondence of lines of seismic action with river valleys and with the long, deep, and narrow mountain lakes is especially noteworthy. Thus the Engadine valley and its continuation in the lake of Como between Bellagio and Como, the lake of Neuchatel with the valley of the Aar, the Rhone below its sharp elbow at Martigny, and the

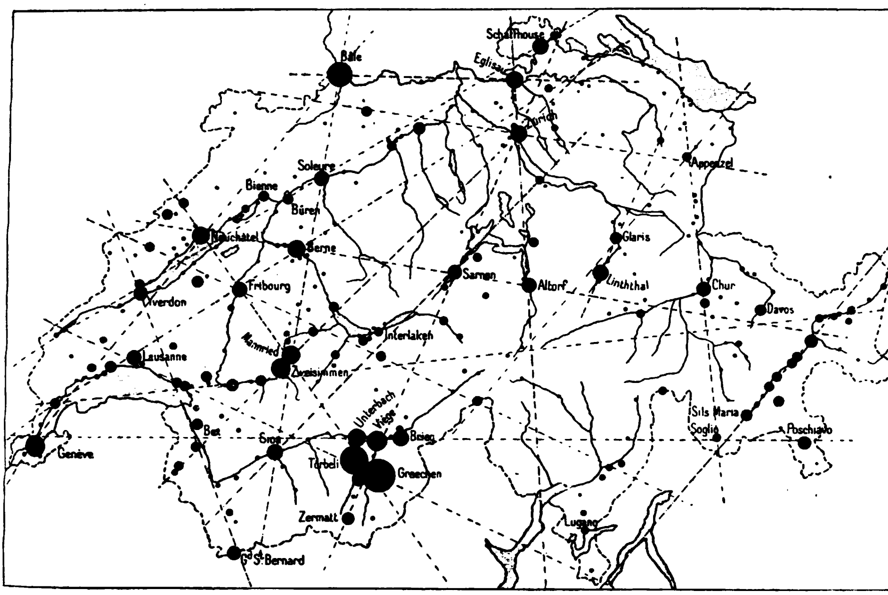

Fig. 5.
Seismotectonic map of Switzerland (Seismic data after de Montessus).

Rhine below Schaffhausen where it follows the margin of the Black Forest — all these come out prominently. In both Figures 4 and 5 the locations of the larger circles which indicate positions of high seimicity, are at the intersections of seismotectonic lines.

Chapter VII.

Seismic geography of the Eastern United States and Canada.

The territory bordering upon the Atlantic coast of North America is one of complex flexures within highly crystalline rock masses —

it is the region which has served as the classical example of processes of mountain building which produce no faults (*Appalachian structure*). This prominence it owes to the early and careful study of it by the brothers Rogers. It is with the New England province of this region that the writer's attention has for the past twenty years been engaged in an attempt to unravel the tangled threads of the geological snarl. Following the example set by the Rogers brothers, as has been done by every geologist who has investigated the region, it was at first essayed to accomplish this object upon the assumption that a complex system of flexures is alone sufficient to account for the present positions and attitudes of the rock masses. Later study of an isolated and complexly faulted basin of Newark (Triassic) rocks which is clearly inset within the crystallines, showed that such an hypothesis is untenable, and that hidden faults must also exist within the crystalline masses themselves.

The methods discovered for indicating the location of probable faults through study of the geology, topography, and hydrography of the province, developed the characters of lineaments as already defined; and it was then attempted to determine in a broad way their distribution within the coastal region from Nova Scotia to Georgia[1]).

The region in question has not generally been regarded as one of high seismicity, and data have in such areas been less carefully collected and preserved. It results from the absence of observing stations and of trained seismologists, that only the heavier shocks and scattered data upon lighter disturbances have been recorded. For the more extended earthquakes; such, for example, as that of Charleston in 1886, the location of a pair of centrums hardly places the seismic data *en rapport* with the geologic and structural. As a centrum is, however, sure to be a locality of high seismicity this limitation of the method of de Montessus is one of incompleteness rather than error. Fortunately, his measure of seismicity includes the considerations of *both frequency and intensity* of shocks, and hence it results that considerable detail in distribution is indicated by his maps. This limitation in his method, it should be stated, he well recognizes, and has made use of epicenters not from a belief in their existence as projections of earthquake origins, but because the available data are to be found in these terms.

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1) Lineaments of the Atlantic border region, 1904.

The map of plate shows the seismic data as worked out by de Montessus[1]) plotted[2]) upon the author's lineament map of the Atlantic coast region; and it appears at once that a most striking correspondence between seismotectonic lines and lineaments exists. Perhaps the most noteworthy coincidences appear in the cases of the Northern Fall Line (H), the Southern Fall Line (I), the Carolina Coast Line (J), the St. Lawrence Line (F), and the Newark Border Line (Φ), the Connecticut and Lower Connecticut Lines (VI′ and 1) the Mohawk-Deerfield Line (Θ), and the St. Croix Line (I′). All the above mentioned lineaments, and to a less degree others as well, are marked out seismogenetically.

Upon the Northern Fall Line are Washington (6) Baltimore (4), Philadelphia (7), Burlington (2), Trenton (2), Princeton (1), Staten Island (1), New York (8), Brooklyn (1), New Haven (3), Guilford (1), East Haddam (145), Milford (1), Newton (1), and Boston (26); not to mention minor points covered near East Haddam (the numbers given after each place are the number of recorded epicenters). This line of epicenters is also extended southwestward upon the continuation of the lineament along the base of the Appalachians. Without an exception the larger circles of seismicity upon this line correspond to its intersections with other lineaments. The seismic importance of East Haddam, where the Fall Line intersects the straight lower stretch of the Connecticut River below Middletown (the strong Lower Connecticut Line 1), is very great; for the locality has first rank in seismicity for the entire region. Ever since its settlement, the town has been frequently shaken by light earthquakes, which have generally been accompanied by rumblings. Indeed the Indian name of the locality, *Morehemoodus*, the place of noises, tells us that this condition has characterized it for an even longer period. The noteworthy localization of the shocks at East Haddam is attested by a letter written in 1729 by the Rev. Mr. *Hosmer* of Haddam to the Rev. Mr. *Prince* of Boston:

"Earthquakes have been here (and nowhere but in this precinct, as can be discovered; that is they seem to have their centre, rise and origin among us), as has been observed for more than thirty years"[3]).

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1) *F. de Montessus de Ballore,* Les États-Unis sismiques. Archives des Sciences physiques et naturelles de Genève, 4th period, vol. 5, 1898, pl. 3.

2) A list of the places and the number of epicenters of each will be found in the appendix.

3) *W. T. Brigham,* Historical notes on the earthquakes of New England 1638—1869. Mem. Boston Soc. Nat. Hist., vol. 2, 1871, pp. 1—28.

The earthquake of May 18, 1729 seems to have been reported only from points upon the Northern Fall Line, namely: Boston, East and Middle Haddam, New York, and Philadelphia. At the time of the Charleston earthquake of 1886, also, it is clear from reports published by *Dutton*[1]) that this line was then one of unusual intensity of shocks[2]).

Nowhere is seismicity so localized within the region, excepting only East Haddam, as upon a line which joins Boston to Portland and is continued northeastward to Augusta and Fairfield (Boston-Augusta Line). This line is the straight coast line of central New England; but its true significance is first revealed when we examine the submerged contours of the ocean floor. The continuation of the line southwestward from New England, after passing over the neighbouring continental shelf, corresponds to the great scarp at the border of that shelf — a cliff on which for more than five hundred miles the ocean floor drops within the space of a few miles from depths of less than 1000 to more than 9000 feet[3]). It was almost exactly upon this line that during the great Charleston earthquake the ships *Crawford* and *Willesdon* felt the shocks, which in view of *Rudolph*'s determination that under-sea shocks are soon dissipated furnishes sufficient evidence that movement was there localized upon this plane[4]).

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1) The Charleston earthquake.

2) The late Professor *George Huntington Williams* of the Johns Hopkins University in a public address delivered at Hopkins Hall shortly after the earthquake in question, drew attention to its apparent localization upon the "Fall Line"; a statement which caused some newspaper comment, but it is not known if it was ever published in a scientific journal.

3) 12th. Ann. Rept. U. S. Geol. Surv., pl. 38.

4) Captain Filton of the *Sam. H. Crawford* when 35 miles off Cape Hatteras heard sounds as of heavy thunder under his vessel. The British ship *Willesdon* while in Lat. 34,16 N. and Long. 75,08 W. felt earthquake with trembling of the ship and the sea suddenly becoming agitated. Captain Lotrop of the *Agenor,* also off Cape Hatteras reported no shock. Of the hundreds of other vessels plying along the Atlantic coast only three reported the shock. The one which received the heaviest shock of all was the *Nina Mathilde,* Captain Allen, which when 37 miles northeast of Charleston light and 12 miles southeast of Cape Romain light, received so severe a shock that the crew were thrown from bed and thought the vessel was on a reef. The location of this point is indicated upon the map. Captain Voegel of the *City of Palalka,* from Charleston to Florida, when fifty miles from Charleston harbor and eight miles off shore felt the shock accompanied by rumbling. This location, as indicated by the map is along the con-

Its position to the continent is similar to that of the Tuscarora scarp to Japan, and by far the greater number of Japanese quakes have been shown to start there.

Upon the line in New England are situated Point Judith (2), East Greenwich (1), Cambridge (4), Salem (2), Boston (26), Newburyport (84), Rye (1), Portsmouth (5), Portland (7), Augusta (2) and Fairfield (1); and all within a distance of 250 miles. The records compiled by *Brigham* show that Newburyport has had a similar history to East Haddam as regards the localization of its shocks and rumblings; while Boston's history has in this respect also been similar, differing only in degree.

The new Shenandoah Valley Line (G) is nearly parallel to the Northern Fall Line and passes through Abington (2), Whiteville (4), Fincastle (1), Deerfield (10), Woodstock (1), Winchester (1), and near Frederick (2), and other points to the northeastward.

Upon the Newark Border Line (*Φ*) are arranged Greensboro, N. C. (1), Ashland, Va. (1), Annapolis (3), Philadelphia (7), Burlington (2), Deerfield, Mass. (10), Turners Falls (1), Peterboro (1), Contocook (8), Laconia (3), and Wolfsboro (4). Another prominent seismotectonic line and one not before indicated upon the map, follows the valley of the Ottawa to Montreal (Ottawa River Line, d), a stretch outside the margin of the earlier map. Another line is given direction by the St. Lawrence (*Δ*), and is prolonged southward parallel to the Newark Border Line (*Φ*) to outline a portion of the western base of the Appalachians.

An additional lineament within the meridional series forms the border of the continental plateau to the east of the Florida peninsula (*T*). This lineament extended northward, passes over the point where the shocks of the Charleston earthquake were felt by the *City of Palalka.* It next passes west of Charleston through Bradley's and Summerville, then along the course of the Great Pedee River, and through the fault gorge separating the Waynesboro from the Deep River Area of Newark rocks. Still further prolonged, past several localities of secondary seismic importance it reaches Buffalo, a city of notably high seismicity.

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tinuation of another scarp bounding the continental plateau. The one remaining instance is of a ship in Hampdon Roads at the entrance to Chesapeake Bay. (*C. E. Dutton,* The Charleston earthquake of August 31st, 1886. 9th Ann. Rept. U. S. Geol. Surv. 1889, p. 528).

Parallel to it is the Cincinnati-Dalton Line (α) upon which are located Cincinnati, Lexington, Mt. Vernon (Ky.), Huntsville and Dalton.

A strongly marked seismotectonic line passes through New York City and is prolonged northwestward to Buffalo and Hamilton, and may be designated the New York-Hamilton Line (λ). Upon this interesting line are Hamilton, Niagara Falls, Buffalo, Addison, Elmira, Morristown, and New York. The northwest shore of the Bay of Fundy, already known to correspond to the course of a fault, is prolonged southwestward along the Maine coast (Maine Coast Line, η), and beyond as a line of noteworthy seismicity. In this extension it encounters the broadly extended arms in the "Trellis" or „Grape-vine" of the Susquehanna River, for which it may furnish an explanation.

The seismic prominence of Whiteville, Va., and Knoxville, Tenn., appears to be in part accounted for by the fact that the line connecting these points is a lineament which to the northeastward borders the scarp at the margin of the continental shelf east of the submerged channel of the Hudson (π). This line crosses Eastern Maryland about on the contact of the Eocene with the Quaternary deposits which occupy the southern portions of the peninsula[1]).

Another lineament which is given direction by the scarp of the continental shelf may be designated the Erie-Wilmington Line (a), and starting at Erie (1) upon the lake of that name may be followed south-southeastward through Deerfield, Va. (10), Lynchburg (1), and Raleigh (1), to Wilmington S. C. (2). To this lineament a noteworthy seismotectonic line is parallel (b). Its position is outlined by the southwestern coast of Chesapeake Bay from Cape Hatteras to Baltimore, and upon it are Rochester (4), Baltimore (4), Addison (2), and Annapolis (3). Two of the five ships which reported the earthquake of 1886 were located at the time on or near the course of this line, and it is doutless a fact of some significance that of the two which were much the more seriously shaken — the one farther south off Cape Hatteras (on this line); and the one near Cape Romain Light — were each located approximately over the intersection of strong lineaments. The prominence of Charleston and Summerville in this earthquake appears to be explained, likewise, by their location at the intersection of prominent lineaments — the Carolina Coast Line (J) with the Meridional Continental Plateau Scarp (T), and a line of the northwest-southeast series which we may call the Charleston-Louis-

1) Mc. Gee, 5th Ann. Rept. U. S. Geol. Surv., pl. 2.

ville Line and designate 10, since it falls into the determined position and direction for this series. Upon that line are Terre Haute (4), New Albany (2), Louisville (2), Mt. Vernon (1), Manchester (2), Summerville (19), Woodstock, and Charleston (17).

The New Jersey-Maryland coast line from Toms River, N. J. extended southwestward across Virginia and North Carolina to Wilmington, is revealed as a seismotectonic line (Maryland Coast Line, Σ). The isolated epicenters of Toms River, N. J., and of Accomac in the eastern peninsula of Maryland, find in this their explanation. Norfolk, Va., and Snow Hill, N. C., are also upon this line. The line e, passes through *Chattanooga*, *Murphy* and *Franklin* near the Appalachians, follows for a considerable distance the fault boundary of the Deep River Newark area of the Carolinas, then intersects Raleigh N. C., the Roanoke river below its elbow, Albemarle Sound, and finally a short stretch of one of the continental border scarps (Murphy-Raleigh Line, e). Its course is thus directed parallel to the Rias Coast and Sound Lines (a and b), which are so clearly marked out farther to the northward.

Had the scope of the earlier investigation been extended to the area of the continental shelf a considerable number of the newly indicated lineaments, here brought to light through their seismicity, would almost certainly have been discovered, for they are all strong lineaments, and with few exceptions also fall into the series as before indicated. Some of these, however, and all of those whose course has here been marked out upon the continent, were before discovered, and in fact entered upon the lineament map; but since the large number of lines seemed to preclude a clear exposition, they were subsequently rejected in the selection of the more important. It will probably be noted that lines other than those now entered upon the map are indicated with some clearness by the arrangement of the smaller seismicity circles, though naturally with less of definiteness than the ones which have been selected. It cannot be assumed that the lineaments along which movement is now most active are the ones of greatest accomplished displacement as faults, and the reverse may even be the case in some instances.

Of the new series, one whose direction is given by the line connecting Rochester with Baltimore is represented by two lineaments; as is also the series in which fall the Ottawa River (c) and Cleveland-Lynn (d) Lines. So far also as comparison is possible the space intervals determined in 1904 to characterise the lineaments of the several series are conformed to by the newly discovered lines.

It will not have escaped observation that the town of Elmira, N. Y., despite its rather low recorded seismicity (one epicenter only), is a place of very special interest for the reason that so many seismotectonic lines are there united. It is a point of radiation of earth fractures of the very first importance. Elmira is situated upon the

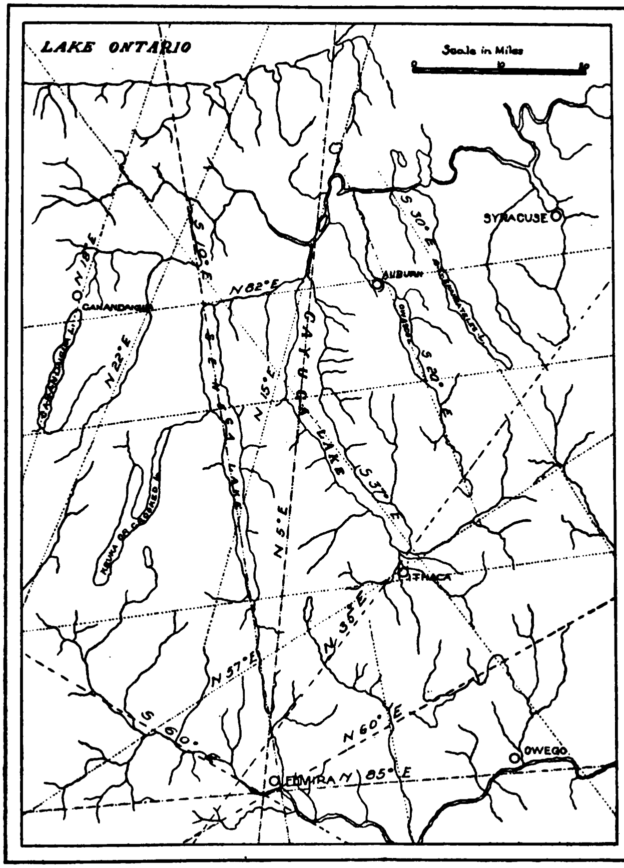

Fig. 6.
Drainage map of the vicinity of Elmira, New York, with indication of control by earth fractures.

border of the well known Finger Lake District of New York, and, fortunately, a very perfect development of the fracture system and a sharply incised drainage have here combined to make possible a tectono-geographic study of the district[1]). Upon the map of Fig. 6,

[1]) Examples of joint-controlled drainage from Wisconsin and New York. Jour. Geol., vol. 13, 1905, pp. 363–374.

reproduced from the paper cited, the strong lines of drainage which meet at Elmira have been indicated together with their approximate bearings. Below are given in parallel columns: 1. the seismotectonic lines which meet at Elmira (from plate 1); 2. the drainage lines which coalesce near the same point (from Fig. 6); and 3. the prominent joint directions of the Finger Lake District as they have been determined by Brown, all directions having less than 6 entries being omitted.

Comparison of Tectonic Elements for Elmira, N. Y.

Seismotectonic Lines	Drainage Lines	Joint Directions	
—	—	N-S	15
N 5 E	N 5 E	—	
—	—	N 30 E	68
N 35 E	N 35 E	—	
—	N 60 E	—	
—	—	N 70—75 E	131
N 80 E	N 85 E	N 80—85 E	97
—	N 60 W	N 60 W	86
N 65 W	—	—	
N 54 W	—	—	
—	—	N 40 W	51
—	—	N 30—34 W	35
—	—	N 20 W	288
—	—	N 15—16 W	88
—	—	N 10—12 W	153
—	N 5 W	N 4— 6 W	43

It is much to be regretted that so little has been done to preserve earthquake records in New England, which, as appears from the map, is a region of high seismicity, notwithstandig the fact that it has thus far escaped quakes of a catastrophic order. Only one of the earthquakes of which Brigham has published records, gives data sufficiently extensive for preparing a seismotectonic map. This is the earthquake of October 20, 1870, for which, fortunately, the directions of the shocks have also been given. In Fig. 7 the places which reported the shocks have been entered together with their direction, and it at once appears that the movement took place on, and the shocks were transmitted along, the lines which intersect in the seismicity circles calculated by de Montessus. The Boston-Augusta Line, the Maine Coast Line, the Northern Fall Line, the Lower Connecticut Line, the Connecticut Line, the St. Lawrence Line, and the Hudson-Champlain Line, all appear to have played some part in

the movement. At the point marked A upon the map, 16 miles northwest of Portland, the tracks of the Ogdensburg Railroad are reported to have sunk ten feet for a distance of 300 feet.

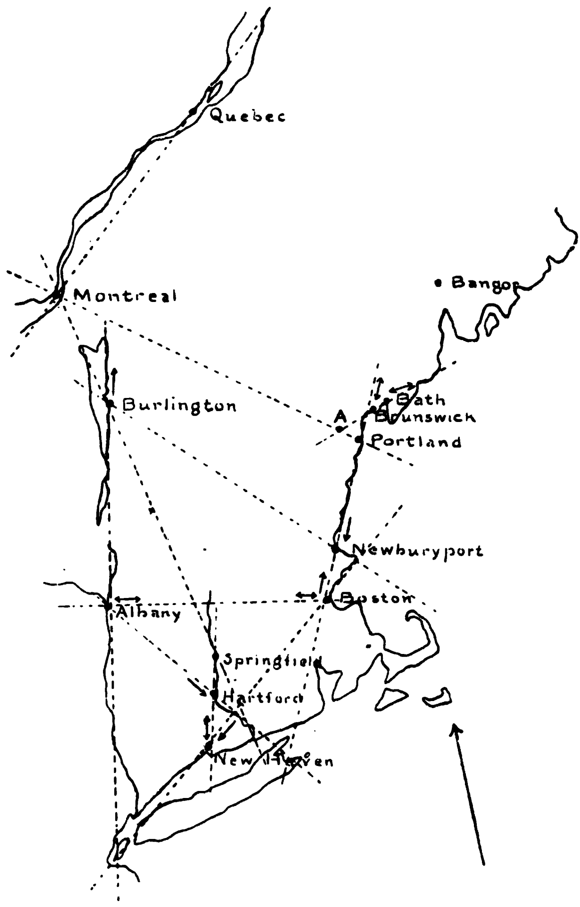

Fig. 7.
Map to show the seismotectonic lines revealed by the earthquake of October 20, 1870 in New England.

It has already been pointed out that the earthquake of May, 18, 1729 seems to have been reported only from points upon the Northern Fall Line. Kemp has shown that the earthquake of May 27, 1897 was clearly related to movements along the Hudson-Champlain fault line [1]). The earthquake of August 10, 1884 was localized along a line "from Washington D. C. to Portland, Me" [2]), while that of March 21, 1903 is described by *Bračič* [3]) as extending from Baltimore to the Gulf of Maine. Of particular interest is the earthquake of Nov. 4, 1877 [4]), which was largely localized on several distinct lines,

[1]) *J. F. Kemp,* 13th Ann. Rept. N. Y. State Geologist, p. 438.

[2]) *C. G. Rockwood,* earthquake of the eastern and Middle States, Aug. 10, 1884. Am. Jour. Sci., [3], vol. 28, 1884, p. 242; vol. 29, 1885, pp. 429—432.

[3]) *V. Bračič,* Erdbebennachrichten aus Nordamerika. Die Erdbebenwarte, Jahrg. III, 1903—4, pp. 205—208.

[4]) *C. G. Rockwood,* Recent American earthquakes. Am. Jour. Sci. [3], vol. 1,5 1878, p. 25.

namely: the St. Lawrence river, Lake Champlain and the Hudson river, the Connecticut river, and the Mohawk river — all of which have been shown above to be seismotectonic lines.

Mc Gee connects the fault along the Hudson with that of the Northern Fall Line, and has pointed out that in both cases the thrown limb is toward the sea. How late the seaward blocks have "dropped" down is shown by the contrast of the drainage to the west with that to the east[1]). That a similar relation obtains between the continental shelf and the coastal plain is indicated by the still unfilled submerged channels of the Hudson and Delaware.

It is of interest to note that the three most prominent seismic regions in the United States — the Atlantic border, the middle Mississippi basin, and the bay of San Francisco — are all proven to be sinking areas[2]); as has been shown also to be true of the Italian peninsula. The Mississippi basin has become known to seismologists through the "New Madrid earthquake" of 1811, and the "sunk country". De Montessus's figures determined to represent the distribution of epicenters within this basin are as follows, exclusive of 28 not definitely located.

Memphis, Miss., 12.	Catlettsburg, Ky. 2.	Anna, Ill., 1.
New Madrid, Mo., 10.	Clarksville, Ark., 2.	Arkadelphia, Ark., 1.
Cairo, Ill., 8.	Clarksville, Tenn., 2.	Belleville, Ill.. 1.
St. Louis, Mo., 7.	Gayoso, Ark., 2.	Carbondale, Ill., 1.
Terre Haute, Ind., 4	Ironton, Mo., 2.	Cincinnati, O., 1.
Evansville, Ind., 3.	Jackson, Tenn., 2.	Eddyville, Ky., 1.
Henderson, Ky., 3.	Lexington, Ky., 2.	Greenville, Ky., 1.
	Louisville, Ky., 2.	Hillsboro, Ky., 1.
	Manchester, Ky., 2.	Huntsville, Tenn, 1.
	New Albany, Ind., 2.	Jasper, Ind., 1.
		Melbourne, Ark., 1.
		Mount Vernon, Ill., 1.
		Mount Vernon, Ky., 1.
		New Harmony, Ind., 1.
		Paduca, Ky., 1.
		Ravensdens Springs, Ark. 1
		Richmond, Ky., 1.

These epicenters have been plotted upon the map of Fig. 8. From this map it is seen that the seismic prominence of Memphis

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1) W T Mc Gee, Geology of Chesapeake Bay. 7th Ann. Rept. U. S. Geol. Surv. (1885—86) pp. 616—634.

2) See *A. C. Lawson,* The Geomorphogeny of the Coast of Northern California, Bull. Dept. Geol. Univ. Calif., vol. 1, p. 263.

is apparently due in part, at least, to the fact that the strong lineament here given direction by the Mississipi River there meets the St. Lawrence Line, which is thus outlined from the estuary of the St. Lawrence river to Memphis, a distance of considerably more than 1000 miles. The Mississipi line itself is a strong seismotectonic line upon which are ranged Memphis (12), Gayoso (2), New Madrid (10), Cairo (8), Carbondale (1)? and Mount Vernon, Ill. (1). The direction of the straight reach of the Mississipi above St. Louis is extended

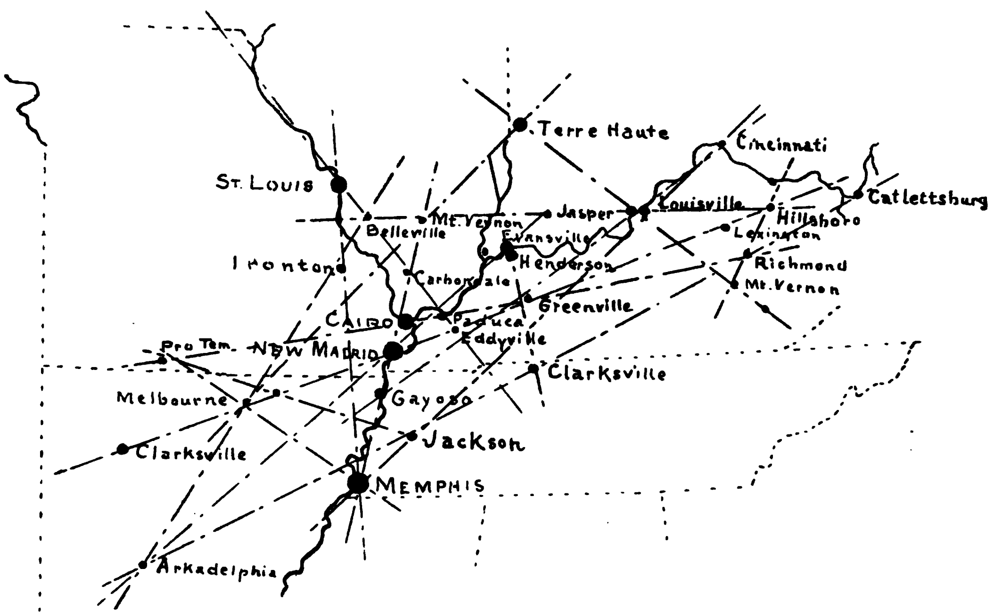

Fig. 8.

Map to show the distribution of epicenters within the area of the Middle Mississipi Basin (after data determined by De Montessus).

southeastward as a seismotectonic line which passes through Belleville, Carbondale, Paduca, and Eddyville. The two most striking lineaments, however, after the Memphis-Cairo reach of the Mississipi, run in a northeasterly direction. On one of these lines are ranged; Clarksville (Ark), Melbourne, Ravensdens Springs, New Madrid, Paduca, Greenville, Lexington, and Hillsboró; while on the other are; Arkadelphia; Jackson (Tenn) Clarksville (Tenn), Richmond, and Catlettsburg. In a nearly equatorial direction another line joins Belleville, Mount Vernon (Ill), Jasper, New Albany, Louisville and Hillsboró.

No less than three parallel lines are indicated trending about N 45° E, and one of these follows the course of the Ohio from Evansville to near New Madrid. As reported by Lyell this was the direction of by far the larger number of fissures produced in the "sunk country" west of New Madrid during the earthquake of 1811.

As was pointed out in the discussion of Calabrian earthquakes, where the fact is one of especially tragic interest, the larger cities have been located at the places of greatest danger. In the working out of a process of natural selection cities of importance are almost certain to be built up at the crossing points of strong lineaments. Should an earthquake of catastrophic violence convulse the areas now under consideration, it can easily be predicted where the damage will be localized.

Chapter VIII.

The significance of lines of abnormal gravity.

No result of the recent studies upon unfelt quakings of the planet is of more far reaching importance than the determination that for the direct earthquake waves the velocity of propagation is practically constant for distances of more than 1000 kilometers; and that though for the longer distances the velocity is about 14 kilometers per second, it is only about 3 kilometers for the shorter distances. There is here no escape from the conclusion that the main mass of the globe is of dense and remarkably uniform composition, and possessed of a rigidity about twice as great as that of the hardest steel. The so-called crust is found to be a mere shell proportionately many times thinner than that of a hen's egg. That the chord of one thousand kilometers of arc (about 9 degrees) should limit the faster and shorter waves, shows that the extreme depth which is attained by a wave travelling along this chord is about 12.5 miles; hence the relatively sharp contact of the lighter and denser material does not greatly exceed half that depth. The average density of the crust that is known to us being about 2·6 and that of the earth as a whole about 5·6, at a depth of about 6 miles the lighter surface shell must be replaced by one of more than twice its specific gravity. Such a deduction leads to most important conclusions when applied to the known phenomena attending earthquakes. The sudden

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1) Principles of Geology, vol. II, p. 108.

crustal movements take place on so grand a scale that they have doubtless on this account alone been sometimes doubted, though supported by well authenticated observations. Dr. *Charles Davison* has estimated[1]) that in connection with the Indian earthquake of 1897 a mass of crust 7000 square miles in extent and 5 miles in depth was subjected to a vertical movement. Milne[2]) after compiling a list of the best authenticated instances in which some measure of the size of the earth mass moved was obtainable, says:

"If it can be admitted that world-shaking earthquakes involve molar displacements equal in magnitude to those referred to in the preceding list — which includes some which have been referred to as world-shaking — then, in the map showing the origins of these microseismic efforts we see the districts where hypogenic activities are producing geomorphological changes by leaps and bounds.

The sites of these changes are for the most part suboceanic troughs. When they occur the rule appears to be that the sea becomes deeper, whilst a coast line relatively to sea-level may be raised or lowered. For nearly all the regions of the world where they take place we have geological and not unfrequently historical evidence that the more recent bradyseismic movements have been those of elevation. This elevation, however, only refers to the rising of the and above sea-level, while the mass displacements seem to be accompanied by sudden subsidences in troughs parallel to the ridges where rising has been observed".

The vertical displacement with reference to each other of such large blocks composed of above less dense and below more dense material, might be expected to bring about local changes in attraction along the mutual borders. With less knowledge than we now possess, but as a result of his extended studies upon the distribution of seismicity over the ocean floor, *Rudolph* in 1887 was led to adopt the view[3]) that the floors of the great ocean deeps attained their position as the result of depression of areas of the crust along planes of dislocation, and that they now represent thinner and lighter blocks. Realizing howewer his inability to furnish adequate proof of this, he wrote:

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1) *C. Davison,* The great Indian earthquake of 1897. Knowledge, vol. 23 pp. 147—150, 169—171.

2) l. c. p. 11.

3) l. c. vol. 1.

"A definitive conclusion upon the question of the constitution of the submarine terrestrial crust can of course only be reached when a sufficient number of measurements of gravity over the open sea are at hand. Pendulum observations upon the sea must hence be regarded as a pressing need of scientific investigation, if we are to come to a better understanding of the structure of the earth's crust and the operation of the geodynamic forces".

The succeeding period has fortunately registered a partial confirmation of *Rudolph's* view, for incomplete as they still are, the observations made appear to point in a single direction.

The first important pendulum observations within the ocean areas were carried out upon islands far from the main land of Asia and especially upon the Island of Bonin. These showed such an excess of gravity over normal values that the last International Geodetic Congress expressed the conclusion that gravity is in general in excess upon the sea and shows a deficit upon the land. Hence the studies of *Hecker*[1]) made upon the open sea while on the journey from Hamburg to Rio de Janeiro, were a great surprise, for the view was expressed that between Lisbon and Bahia the variations in gravity were so small that it might be regarded as normal and in correspondence with what it should be in the same latitudes and at sea-level upon the land.

De Lapparent has, however, drawn most interesting deductions from these determinations by showing that the variations actually observed are in direct relation to the gradient of the ocean floor along the line traversed[2]).

He shows that in *Hecker's* data obtained between Lisbon and Bahia, there are maxima of abnormality: 1. at the sudden passage from the Gettysburg Bank to the great deeps near the Canaries, 2. at the rapid descent of the sea floor between St. Paul's island and the equator, and 3. at the rapid rise near Cape St. Roque, Brazil. From Hamburg until over the descent at the north of the Bay of Biscay the variations in gravity did not exceed 15 units, whereas they here increased to 177. Remaining near zero along the coast of Portugal they suddenly increased to 152 off the mouth of

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1) *Helmert, Dr. Hecker's* Bestimmung der Schwerkraft auf dem Atlantischen Ozean. Sitzungsb. d. k. preuss. Acad. d. Wiss. z. Berlin, vol. 8, 1902, pp. 123—126. Also *Hecker,* Veröffentl. d. k. press. geodät. Inst., 1903.

2) *M. A. de Lapparent,* Sur la signification géologique des anomalies de la gravité. C. R. Acad. Sc. Paris. vol. 137, 1903, pp. 827—831.

the Tagus near a descent to 5000 meters. De Lapparent further points out that the earlier determinations made at Bonin, upon which in largest measure the excess of gravity over the ocean areas was assumed, were made upon a sharp and narrow ridge bordered on both sides by ocean deeps with rapid descents to depths of over 6000 meters. The excess of gravity over normal was here no less than 257 units. In the Atlantic, however, over the flat floor with depths of 3800 to 4500 meters, the values were nearly normal.

Two other instances in point have been added from Northern Russia and India[1]). In the former region the great triangle Kamienesk-Podolsk, Kazan, Astrakhan is relatively to the surrounding country very unstable, and has been shown to have a margin of dislocations. The measurements of gravity by General *Stebnitzki* have shown that a zone of deficit of maximum gravity with reference to the surrounding country likewise corresponds to this margin. *De Montessus* adds:

"One has thus in northern Russia an approach to a three-fold coincidence between a band of relative instability, a zone of dislocation, and a line of maximum of abnormality of gravity".

It should be pointed out, that the most marked changes in the value of gravity which were observed by *Hecker* between Lisbon and Bahia, are not only the zones of deepest slope but possess the highest seismicity yet observed by direct methods within the area of the Atlantic Ocean.

In India the great northern border of the plain of the Indus and Ganges from the Salt Range to Bhotan, is similarly a zone of high seismicity in coincidence with the dislocations along the south flank of the Himalayas. The southern portion of this plain, on the contrary, is quite stable. In 1901 *Burrard* showed that the plumb-line is deviated toward the south or the north according as one observes to the north or the south of a line joining Calcutta to the center of Radjpoutana.

The most valuable investigation yet carried out to determine the distribution of anomalies in the value of gravity with reference to a definite area, has been made by an Italian, Professor *Riccò,* the eminent Director of the Observatory of Catania, Sicily; whose

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1) *F. de Montessus de Ballore,* Sur les anomalies de la pesanteur dans certaines régions instables. C. R. de l'Acad. sc. Paris, vol. 136, 1903, pp. 705—707.

observations embrace the South Italian peninsula, Sicily, and the Eolian islands [1]).

Riccò finds that gravity, which is perfectly normal at the summit of Etna, on the Apennines, and to the northward of Naples, is constantly but not uniformly augmented when one descends toward the sea. The excess measured in meters of acceleration is 182 at Stromboli, 151 at both Lipari and Pizzo, 174 at Augusta (between Catania and Syracuse), and 114 at Castellammare di Stabia near Naples. Observations made at 43 Stations allow *Riccò* to trace the iso-abnormal curves. These conform in direction to the borders of the Tyrrhenean and Ionean seas. A relation also holds between the districts where the iso-abnormal lines are most crowded and the districts of highest seismicity. The great Tyrrhenean deep lying between Italy, Sardinia and Sicily has depths of 3000 to 3731 meters, and steep bounding walls which *Suess* [2]) and later *Cortese* [3]) with greater detail have shown to be the position of fault planes. Hardly less steeply do the slopes descend toward the deep of the Ionian sea, in which a maximum of 3968 meters is reached. Despite these great depths the view of *Suess* [4]) that the Mediterranean floor represents the submerged portion of a great land area of which only the remnants are now visible, is supported by equally strong evidence from the domains of tectonic geology and paleozoology. The great importance of *Riccò's* observations has been emphasized by *de Lapparent* [5]).

From quite another quarter evidence has been contributed toward the solution of the problem under discussion, and this has come about as a result of work by the British Association. At Professor *Milne's* request those observing stations which submit reports to the Seismological Committee and which were provided with magnetometers submitted reports upon the behaviour of these instru-

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1) *Annibale Riccò*. Determinatione della gravità relativa in 43 luoghi della Sicilia orientale, delle Eolie, e della Calabria. Memorie della Società degli spettroscopisti italiani, vol. 32, 1903, pp. 173—296. A brief summary is, Riassunto delle Determinazioni di gravità relativa fatte nella Sicilia orientale, in Calabria, e nelle isole Eolie. Rendiconti della R. Accad. dei Lincei, vol. 12, 1903, pp. 483—490.

2) *Ed. Suess,* Über den Bau der italienischen Halbinsel. Sitzungsber. d. k. Akad. d. Wiss. z. Wien, Math-naturw. Cl., vol 65, 1872, I. Abth., pp. 1—5.

3) *E. Cortese,* Descrizione geologica della Calabria, Mem. desc. della Carta geolog. d'Italia, vol. 9, 1895, XXVIII and 310, map and plates.

4) *E. Suess,* Über die einstige Verbindung Nord-Afrikas mit Süd-Europa. Jahrb. d. k. k. geol. Reichsanst., vol. 13, 1863, pp. 1—5.

5) l. c.

ments during the passage of unfelt earthquake waves. It was thus learned that whereas in some stations the disturbances were so great that they were utilized as seismologic records, other stations, and particularly the large number located in England, reported no influence whatever. Professor *Milne* is not inclined to trace these disturbances to mechanical causes, but would rather regard them as magnetic perturbations. He says further[1]):

"If such an explanation as this is true, then in the vicinity of the stations where earth-waves produce marked disturbances of magnetic needles we should expect to find evidence of the existance of a hidden chain or mass of unusually dense material. In other words, the value of *g* observed at these stations should be greater than at those stations where magnetic needles are not disturbed — *caeteris paribus*".

At Batavia and Bombay, at which stations gravity is respectively 114 and 135 units in excess of normal (or about twice the variation determined for the English stations) the perturbations of the magnetometers are so common at the time of earthquakes that they have seismoscopic value and along a line of dislocation Bombay has already been put in relation to a line of displacements by *Burrard.*

Milne's view regarding the origin of the perturbations of magnetometers seems to have been confirmed by a recent study of *Riccò's* which treats of the eastern coast of Sicily[2]).

The lines of equal magnetic declination as determined by Palazzo are deflected from the normal course where they cross the intense seismic zone of the Val di Noto (Noto-Mineo), and the line of horizontal intensity of magnetism 0,252 suffers a sharp deflection in crossing the great fault of the Straits of Messina, likewise a zone of high seismicity. While these local variations may in part be traced to the magnetic character of recent lavas it does not appear that they can be wholly so explained, and *Riccò* says;

"We may therefore conclude that also in eastern Sicily we have the three-fold coincidence of singular instability, or seismic activity, with noteworthy anomaly of gravity and irregularity of the terrestrial magnetism" (p. 3).

It should be noted that by far the most remarkable local vari-

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[1]) *John Milne,* Seismological Observations and Earth Physics. The Geographical Journal, London, vol. 21, 1903, pp. 16—18.

[2]) *A. Riccò,* Anomalie del magnetismo terrestre in relazione alle anomalie della gravità nella Sicilia orientale. Boll. dell'Accad. Gioenea di Scienze naturali in Catania. Fasc. 80, 1904, pp. 1—3.

ations in the horizontal intensity of magnetism which have been found in greater Italy are clearly upon the island of Sardinia, and near large extravasations of basaltic lava [1]).

There are recent volcanoes upon Sardinia which ejected trachytic rock, but the position of the two great vents that yielded basaltic material seem so clearly to be in relation to the abnormal magnetic lines that the position of other centers has less significance. It is difficult to say what relation the abnormal lines here have to lines of fracture.

The scattered observations which have been brought together in the above paragraphs are but beginnings, though significant ones; and it seems certain that the near future will bring many studies of a like nature. There is in the results an indication that the local values of gravity are altered as the result of local displacements which produce earthquakes. It is quite possible that definite proof of this will be secured through the labors of a Royal Italian Commision of experts which includes Professor Riccò, and which as a consequence of the recent disastrous earthquake in Calabria is to repeat his observations upon the value of gravity throughout the district affected.

Like the quite different studies of *Milne*, *de Montessus*, and *Rudolph*, the pendulum observations by *Riccó* and others are trending in the direction of a study of the physics of the planet in sections so large as to constitute an appreciable fraction of its surface. Seismology is thus fast forging a link to connect geology upon the one hand with astronomy upon the other.

Chapter IX.

A conception of the cause and nature of earthquakes.

A general belief among geologists, probably well founded, traces the differential movements of the earth's crust largely to the action of gravitation, the general result being assumed to be a contraction of the surface shell through secular cooling, though doubtless modified by many other causes [2]). If this be true, it follows that should large

1) *Luigi Palazzo,* Carta magnetica delle isodinamiche d'Italia. Atti del V. Congr. Geog. Italiano, Naples, 1904, vol. 2, Sez. 1, (Scientif.) pp. 51—72.

2) *C. R. Van Hise,* Eaith movements, Trans. Wis. Acad. Sci. etc., vol. 11, 1898, pp. 465—516. Also, Estimates and causes of crustal shortening. Jour. Geol., vol. 6, 1898, pp. 10–64.

enough fractions of the earth's surface be taken into consideration, the average movements of the masses are in the direction of the center of the planet — though the movement of some of its parts may be in the opposite direction with reference to their neighbors, or even in reference to the earth's center. Speculation upon the physics of the lithosphere has been greatly simplified by the valuable generalization of *Van Hise* regarding the state as regards mobility of the rock material. *Van Hise* has shown that in consequence of pressure from superincumbent material at depths subject to considerable range owing to variation in rock material, to local variations in the depth of isogeotherms, and to other causes, but which may be placed at about six miles upon the average, all rock-pores must be closed[1]). Under the conditions which obtain below this depth, a rock could not be deformed by fracture, and sufficiently large differential stresses must result in flow similar to that of an extremely viscous fluid. This lower zone of the crust he has designated the *zone of flow*, and the superincumbent and outer shell the *zone of fracture.* Lack of homogeneity of rock material, and other conditions, make it necessary not only to assume for the zone of flow a very irregular surface, but to take into account a relatively thin intermediate layer — the *zone of combined fracture and flow.*

From what has been set forth above in the last chapter it would appear that the surface level of the zone of flow cannot be far removed from the rather sharp zone of contact which separates the denser and more elastic core of the earth from the outer and relatively inelastic shell.

Considerable confusion seems to have been introduced into tectonic studies by considering together the fold and fault structures when both are present together in the rocks: as confusion has also arisen because dislocations along thrusts have not been separated from those on steep joint planes. The writer has pointed out[2]) that whenever in complexly folded rocks a system either of joints or faults can be made out, the origin of the folds must antedate that of the joints or faults. Were this not the case, it would be impossible to assume that flow had taken place when the folds were produced. A relief, more or less complete, from a condition of stress within a section of the earth's crust may be assumed to bring about folding

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[1]) *C. R. Van Hise,* Principles of North American Pre-Cambrian Geology, with an appendix on flow and fracture of rocks as related to structure, by *L. M. Hoskins.* 16th Ann. Rept. U. S. Geol. Surv., 1895, pt. I, pp. 581—872, pls. 108—117.

[2]) The mapping of the crystalline schists. Jour. Geol., vol. 10, 1902.

within the zone of flow at the same time that it produces a network of faults within the outer zone of fracture. Progressive denudation brings the lower shells of the crust successively nearer to the surface, so that subsequent deformations brought about in a similar manner induce in them systems of fractures which are superimposed upon the folds already present.

Fracture systems due to earth stresses well up in the zone of fracture seem to be largely composed of surfaces which are essentially radial as regards the center of the planet, and are essentially plane, at least for small provinces. This general conclusion is confirmed by a wide range of observations by many geologists and practically in all quarters of the globe; joint planes in rocks which have not been tilted since their formation being universally found nearly or quite vertical. These observations have been supported by experiments upon failure, both by compression and tension, of elastic bodies like glass [1]), as they are also by purely theoretical studies of elasticians [2]). From the supposition that the resultant from all the conditions tending towards change of volume within the outer shell of the earth results in a contraction; it is likely that compression plays a much more important role than tension in bringing about systems of fracture.

Though comparatively little has yet been accomplished in gathering data upon the orientation of fracture systems in different areas, enough evidence has been collected to indicate that in a broad way at least correlation is possible over large areas, and that for each province subjected to geological investigation it is necessary to go outside that province in seeking the cause of the deformations observed [3]).

The evidence reviewed in the above chapters, but especially that collected by de Montessus, reveals the fact that in an overwhelming majority of instances it has been possible to connect earthquakes with movements along fault planes. In a few instances, however, earthquakes have been recorded from districts of folded rocks in which faults have not been described; and de Montessus has suggested

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1) *Daubrée and Tresca,* Géologie expérimentale, vol. 1.

2) Geo. *F. Becker,* Finite homogeneous strain, flow and rupture of rocks. Bull. Geol. Soc. Am., vol. 44, 1893, p. 50.

3) The correlation of fracture systems and the evidences for planetary dislocations within the earth's crust. Trans. Wis. Acad. Sci., vol. 15, pp. 15—29 (Separates issued in advance of general publication, August, 1905).

the possibility of their arising as an incident to folding[1]. The small number of instances were earthquakes have not originated in regions of known dislocations, militates strongly against such a view; while the difficulties known to attend the determination of faults makes their probable presence even where they have been undiscovered a much simpler explanation. We shall here consider earthquakes as due to crustal movements on steep and generally vertical planes within the fracture zone of the lithosphere.

The assumption of the potentially fluid substratum within the earth at a moderate depth below the surface requires the disappearance of the fracture planes within the superficial shell of the earth so soon as they reach the substratum. The support of the orographic blocks outlined by the fractures, is further to be regarded as hydrostatic; an assumption which comports well with the known adjustments that have taken place in faulted regions, such, for example, as the "Great Basin" of the western United States. The high elasticity of the zone of flow for rapidly moving impulses, such as earthquake waves; would thus appear to be in striking contrast with its plasticity in respect to slowly acting differential stresses.

The stress system to which the fractures of the earth's outer shell is to be primarily ascribed, was doubtless made up largely of lateral or horizontally directed components, and from what has been said, may be regarded as essentially regional, and perhaps planetary, in its extension. Such stresses can hardly account for the changes of level brought about in earth blocks, since these must depend upon local conditions of adjustment of support to load.

In a discussion of the conditions attendant upon the depression of a circumscribed area of the earth's crust, we must start out from the assumption that within that area support has been less or load greater (perhaps both) than within the surrounding territory. A block which is tending toward elevation has these conditions reversed. If in the first instance, which may here serve for illustration, we choose to consider that the territory surrounding the area is acted upon by resultant stresses the direction of whose action is upward, the result is not changed. Somewhere between the local area and the surrounding territory a line may be traced, at all points of which the resultant stress in a vertical direction is zero. This margin

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1) *F. de Montessus de Ballore,* Essai sur le rôle seismogénique des principaux accidents géologiques. Bull. de la soc. belge de geol., vol. 17, 1903, Reproductions, pp. 49—68.

of the area we have called the *line of no vertical stress*[1]), which may be looked upon as a line of fulcrums from which the moments of load must be computed.

To illustrate what may be conceived to take place at the time of an earthquake, let the area of Fig. 9 be a portion of the earth's crust which is tending toward depression, and let the curving line A B E F C H G be its margin — the line of no vertical stress. The fracture system present, greatly simplified, is represented by the

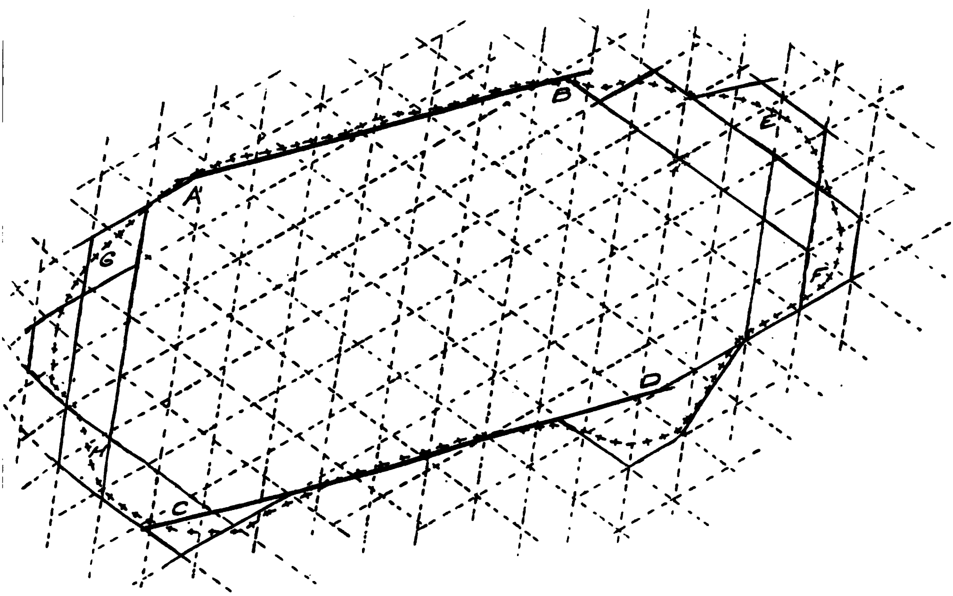

Fig. 9.
Diagram to illustrate a theory of earthquakes. The dotted lines are the traces of the fracture system with the surface. The curving line A B E F C H G is the line of no vertical stress. The lines A B and C D not in correspondence with planes of the fracture system are new dislocations formed at the time of earthquakes. The other full lines of the figure are faults on old fracture planes.

network. Where for long distances the line of no vertical stress takes a direction not in correspondence with any plane of the fracture system, new dislocations have been represented as forming; whereas in those stretches where changes of direction are frequent the dislocations are shown as adjustments along old planes of fracture and

1) ***William Herbert Hobbs,*** The Newark system of the Pomperaug Valley, Connecticut. 21st. Ann. Rept. U. S. Geol. Surv., 1901, pt. III, pp. 1—162. (Chap. IV, Sec. 6, Origin of the fault system, pp. 121—132).

here distributed over a number of surfaces. Reverse the direction of the stresses, so as to represent an area tending toward elevation, and such an explanation may be applied to the earthquakes of Owens Valley in 1872, Sonora in 1887, or Japan in 1896. In all cases displacements of the nature of adjustments must be supposed to take place along many of the other fracture planes of the area and its immediate neighbourhood.

From all planes along which movement takes place, elastic waves are propagated and arrive at any given point of the disturbed district at different times, in different azimuths, and with different angles of emergence. The motions of a particle under their combined action is well illustrated by the wire models prepared by the late Professor

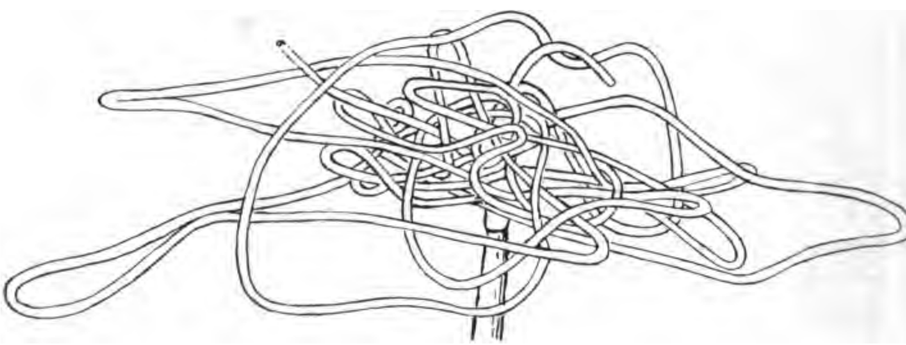

Fig. 10.
Wire model to show the nature of the registered motions (magnified) of a particle at a single observing point during the Japanese earthqnake of January 15, 1887. The Model covers the second twenty seconds only of the disturbance. (After Sekiya.)

Sekiya upon the basis of registered movements in connection with the Japanese earthquake of 1887[1]). One of these interesting models is reproduced in Fig. 10.

The difference in time in the arrival of waves at any observing station arises not alone from the different distances travelled, but from differences also in actual time of occurrance. With the initial movement of an earthquake must come a reduction in the potential energy of the stress system and a redistribution of stresses for the district; a change which will recur with each succeeding shock. The succession of shocks may thus bear considerable resemblance to that

1) *S. Sekija,* A model showing the motion of an earth-particle during an earthquake. Trans. Seismol. Soc. Japan, vol. 11, 1887, pp. 175—177, pl. 2.

attending the formation of a series of cracks in the ice-covering of a mill-pond when the water is being drawn away at the race.

Observations made especially by observers of the Austrian school indicate that earthquake shocks are transmitted with least loss of intensity along the fracture planes, and the writer's studies upon Calabrian quakes have shown that destructive intensity is greatly augmented at the intersections of these fissures[1]).

In an application of our theory of earthquakes to the Italian province we may proceed a step further and consider the cumulative effects of the successive seisms upon the altitude relative to sea level of the land area. It will be noted that the principal seismotectonic lines indicated upon the map vary but slightly except in their greater number from these which were determined by Professor *Suess* in 1871 as the great tectonic lines of the province[2]). As regards the changes in altitude it is apparent that we have here to do with a problem of *descent* of land masses. It was long ago shown by *Suess*[3]), and later confirmed by *Cortese*[4]) that the Tyrrhenian and Ionian seas doubtless represent the sunken blocks of a larger continent; of which now only fragments remain in Italy, Sicily, Sardinia, Corsica, and the smaller islands. Issel has shown[5]) that an elevation of the coasts of all the larger of these landmasses has been definitely determined to have occurred in recent though prehistoric time. This may perhaps be traceable to a sort of isostatic adjustment consequent upon the sinking of the sea floor. A widely distributed series of observations would indicate that within historic times the coasts have been steadily sinking[6]), a movement which must be accelerated with each succeeding earthquake. The only portion of the coast where an elevation has been determined to be now in progress is the narrow stretch of Sicilian coast-line to the west of Palermo. Professor *Agamennone* has told the writer that at the

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1) See the following monograph.

2) *Ed. Suess,* Die Erdbeben des südlichen Italiens. Denkschr. d. k. Akad. Wiss., Math.-naturw. Kl., vol. 34, pp. 1—32, 3 pls.

3) *Ed. Suess,* Über die einstige Verbindung Nord-Afrikas mit Süd-Europa. Jahrb. d. k. k. geol. Reichsanst., vol. 15, 1863, pp. 1—5.

4) *E. Cortese,* l. c.

5) *Arturo Issel,* Le oscillazioni lente del suolo o bradisismi, etc. Atti della R. Università di Genova, vol. 5, 1885, figure on page 176.

6) There are other observations which point to a noteworthy constance at least of certain sections of the Italian and Dalmatian coasts.

time of the earthquake in the Laziale region in 1899 his impression of a distinct settlement of the ground was unmistakable. Professor *Suess* in a personal letter, says: "I really believe it not quite without the limits of possibility, that one day a greater catastrophe may occur, and that a part of Calabria or of Sicily sink to the depths".

In the differential movements of the crust within the Calabrian province, the several larger masses of more rigid rock material — the Sila, Cocuzzo, Pecoraro, Aspromonte, Peloritani and Cape Vaticano masses — have each acted as units, as is pretty clearly shown by the segregation of the disturbed communes along their margins. There have also been differential adjustments of lesser magnitude within each of them. Where their margins as plotted upon the geological maps are undulatory in their course (largely owing to the characteristic superficial torrential deposits), the courses of the seismotectonic lines which so nearly coincide with them, reveal the probable position of the buried contact upon the fault plane.

Chapter X.

Restatement of law of distribution of seismicity.

The identification of lines of seismic activity with strong earth lineaments, makes it necessary to reexamine de Montessus's laws of distribution of seismicity; for it is not always true of these lines that they correspond to the steepest slopes. Thus by far the most prominent seismic line of the Eastern United States — the Northern Fall Line — is for much of its extent, and here the more seismically active portion, hardly a line of relief at all. Much the same may be said of the two lines which stand next in importance — the Boston-Augusta Line, and the St. Lawrence Line. The first mentioned, *extended*, is found to be the most remarkable scarp either upon or near to the continent; and, similarly, the Northern Fall Line to the southwest of Washington follows the base of the longest steep slope to be anywhere found within the land area here under consideration. The law of steepest slope would therefore apply to *portions* of many, if not to the greater number, of seismic lines. In some way, however, — be it in the geologic contacts, in the arrangement of falls, in lines of drainage, in coast-lines, or in relief — all the seismic lines are lineaments; which without too great liberty we

may now frankly designate lines of fracture — faults, let the throw be what it may.

De Montessus's laws may, therefore, be compressed into one:

Seismicity is localized on earth lineaments — faults — and is greatest at their intersections.

The intersections corresponding to the highest order of seismicity in the case of particular earthquakes have generally been determined as the epicentrums of those disturbances, since epicentrums are localities of heaviest shocks. Should new maps be prepared for each seismic province and for each earthquake within them, by locating each village damaged and designating by a numerical figure its seismicity for that disturbance; a composite map to include the data from all the others should afford results the same in kind but of far greater refinement. It may be inferred that such a method would be the most sensitive one for discovering the fracture system of the province, unless a microphonic study of *brontidi* should be found practicable within the region.

The value of the methods which have been discussed above must be measured with due consideration of their common attribute of revealing facts not disclosed by the methods generally in use, and which facts might, therefore, otherwise have remained undiscovered. As regards the provinces of low seismicity, one may have a deep interest in unraveling their tangled geologic structures and not have the hardihood to invoke an earthquake in order to sensitize the province for cartographic processes. There will, however, always be possible a scientific study of the scenery, which may be analyzed in terms of mountain and valley, cliff and plain, river and coast. A lineament may be in one of its sections a scarp, be continued in a different type — let us say as a drainage line —, and this again may be extended by a third — it may be as a "fall line" which intersects lines of drainage —, and this again by a geologic boundary, etc.; a composite nature which tends to conceal its presence.

The observation made on the ground that the course of a line of dislocation is most frequently not straight, but made up of a great number of straight elements composing a series of zigzags, is indication that lineaments which appear rectilinear upon the maps, may be so only in proportion as the scale of the map is small. Such lineaments if traceable to dislocation of the crust for the control of their direction, must be conceived to outline in the majority of instances a complex but comparatively narrow zone of displacements,

in which other directions than that given by the general trend are included. The principal dislocation, while making excursions in zigzags to either side of its axis does not, it would seem, deviate very far from this average course. Such lines, if in reality the projection of approximately plane surfaces within the crust of the earth, will, upon maps constructed upon a polyconic base, appear as curves — the projection of great circles. This necessary correction in their delineation, like the influence of erosion in everywhere moulding curving outlines, has often effectively obscured the architectural lineaments of the landscape. Likewise the heavy black overprinting of the culture, with its highways and lines of railway, adds a further distracting element; and the architectural peculiarities are for these reasons so little likely to force themselves upon the attention that the key to their system will have to be sought out.

Looking upon a fault system as outlining a series of orographic blocks which have taken up their present positions through adjustment on bounding surfaces, like the stones within a mosaic; we see that throw is likely to take on sudden and often great changes, and may (when adjacent blocks stand at the same altitude) disappear entirely. The structure, however, continues, and a resumption of the dislocation may be looked for on the continuation of each lineament, just as the basalt dikes of the British Isles are interrupted and after an interval appear on the same line extended[1]).

The fact that lineaments can be followed along the course of a great circle of the globe for distances of a thousand miles and more, marked out not only as topographic and geologic breaks — nearly always as both — but now clearly revealed as faults along which movement is even today in progress; shows beyond question that we have here to do with conditions which effect the earth as a whole, and which are in respect to their magnitude astronomic in their nature. The first suggestion of such a connection based upon observation seems to have been made by Suess in his study of a region in Eastern Africa[2]). The stronger lines of dis-

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1) *A. Geikie,* The lava fields of northwestern Europe. Nature, vol. 23, 1880, pp. 3—5.

2) *Ed. Suess,* Die Brüche des östlichen Afrika. Beiträge zur geologischen Kenntnis des östlichen Afrika, by *v. Höhnel, Rosinal, Toula* and *Suess:* pt. IV, pp. 135, 139. (Special reprint from Denkschr. d. k. Akad. d. Wiss. z. Wien, Math.-nat. Kl., vol. 58, 1891, pp. 555—584.

placement being there, as in many other regions, meridional or nearly so, Suess has suggested that they are connected which fracturing of the planet considered as a whole. We quote:

"The considerable part of the earth's meridian included within the area shows that we have here to do with dislocations which are at least of the order of the furrows upon the moon, if this be a very distant comparison". (P. 135) . . . .

"The occurrence of such great meridional clefts might easily lead to the view that there is present throughout a tendency toward meridional fissuring of the planet in the direction of its meridian; and indeed, so much the more, since the lines of the Laccadive and Maldive islands and the greater number of meridional fractures in the faulted country of the basin range of North America appear to confirm such an hypothesis". (P. 139).

The late much lamented Freiherr *v. Richthofen* has by his recent studies from Eastern Asia[1]) made a most important contribution to this subject. He has clearly shown that the grander features of the entire Pacific Coast of Asia are arranged within a system or network and enclose tilted plateau-like blocks. The arclike boundaries of these blocks give form to the great plateau area, to the Asiatic coast line, and to the festoons of islands which fringe the latter. The meridional and diagonal series of lineaments *v. Richthofen* found to be in each instances tectonic lines of displacement; the equatorial series, which joined to the meridional one has produced the arcs, is in part explained by a system of flexures.

The individual tectonic lines of the Asiatic series are in some

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1) *Ferdinand v. Richthofen,* Geomorphologische Studien aus Ostasien. Sitzungsber. d. k. pr. Akad. d. Wiss. z. Berlin.

I. Über Gestalt und Gliederung einer Grundlinie in der Morphologie Ostasiens, vol. 39, 1900, pp. 888—925.

II. Gestalt und Gliederung der ostasiatischen Küstenbogen, vol. 36, 1900, pp. 782—808.

III. Die morphologische Stellung von Formosa und den Riukiuinseln vol. 40, 1902, pp. 944—975.

IV. Über Gebirgskettungen in Ostasien, mit Ausschluss von Japan. Ibid., vols. 38—40, 1903, pp. 867—891.

V. Gebirgskettungen in japanischen Bogen. Ibid., pp. 892—918.

Reviews and partial translations of the above papers the author has printed in the American Geologist, vol. 34, 1904, pp. 69—80, 141—151, 214—226, 283—291, 371—378.

cases 700 and more miles in length, and continuous, although zigzaging lines nearly cross the continent.

During the past year the author made a critical comparison of the fracture systems described from different portions of the United States, with the result of finding that a noteworthy correspondence exists in respect to orientation [1]). The meridional direction brought out so prominently in the above mentioned studies by *Suess* and *v. Richthofen* was there also found to have the greatest importance. Almost as frequently, however, fractures were found to follow approximately the courses of the earth's parallels and the intermediate directions of the diagonals. In a very considerable number of districts the prominence of these four directions was quite noteworthy. Whereas the meridional and equatorial fractures were found to be fairly constant in their directions, the directions of the diagonal fissures are much less definite, and several series are clearly involved.

This series of essays cannot be more fittingly concluded than by quoting a passage from the writings of the distinguished Professor *Kjerulf*, once the Director of the Geological Survey of Norway; whose clear and prophetic vision reached far beyond the horizon of conventions of his time. Speaking of the tectonic lines clearly revealed by the then new and accurate topographic maps of his country, his trenchant and picturesque sentences ring true to-day as when first uttered [2]):

"Intersected by these lines the sunken strips of land came into existence in the surface, and if one could only find an observation point distant enough he would see that they run in straight lines . . ."

Furthermore these lines are nothing less than those which upon the entire earth condition the relief of the land surface; but Norway shows them particulary well imprinted in its fjords and valley depressions with their straight and angular margins and their water-filled basins. If these lines do not stand forth so sharply upon the older maps, then the method of drawing is at fault, since it is not adapted to reveal the true expression. The valleys are curved in serpentine lines like an S, as are also in many cases the angles and projections of the fjords; while the mountain ranges appear rounded

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1) The Correlation of fracture systems and the evidences for planetary dislocations within the earth's crust. Trans. Wis. Acad. Sci. etc., vol. 15, 1905, pp. 15—29 (separates issued August, 1905 in advance of general publication).

2) *Theodor Kjerulf*, Die Geologie des südlichen und mittleren Norwegen. Authorized German edition by *Dr. Adolf Gurlt*, Bonn, 1880, pp. 329—334.

off like ovals or oyster shells. The general maps also are in this respect no better, because they give expression through equally distant one thousand foot contour lines instead of by angular forms. In this manner quite rectilinear mountain ranges disappear into curves, with only the mountain peaks standing out like points which have been left. By means of such general maps the eye is led astray from the most important facts, and there are evolved theories of erosion and of excavation by ice through small agencies acting through millions of years, while the true lines of Nature point out a work which could have been brought about perhaps through a single process of compression. If one should outline, upon the other hand, in the general maps the true leading lines in which the surface of the land is cut through by large and far reaching intersections, they would be shown to be always fracture lines, dislocations, dike lines, and axis lines.

Thus are formed the great systems of clefts which cut up the earth's surface — the fundamental lines for the aspect of the surface of Norway. The mysterious network of these lines is stamped in indelible characters. It may, indeed, remain a long time undiscovered, but if one has ever seen it, it will never again escape his observation. Like a moss-grown inscription upon a slab of marble, it is there and can be recognized. Here all embodied representations of plateaus, tilted plains, and erosion of every kind; have not availed to hide the writing and withdraw it from observation: push them all aside and the eye again distinctly sees the Runic characters — and it depends only upon this that they be all correctly deciphered in the future".

Appendix.

Distribution of earthquake epicenters within the eastern United States.

(Arranged from the lists prepared by the Count de Montessus and published in the *Archives des Sciences Physiques et Naturelles de Genève* in 1898 under the title *Les États-Unis sismiques).*

1. Places of more than two epicenters each.

East Haddam, Conn., 145; Newburyport, Mass., 84[1]); Boston, Mass., 26; Summerville, S. C., 19[2]); Charleston, S. C., 17[2]); Montreal,

[1]) Also "Salem and Newburyport" 1.

[2]) Also "Sumerville and Charleston" 8.

Can., 10; Points de Monts, 10; Deerfield, Mass., 10; Deerfield, Va., 10; Contocook, N. H., 8; Ottawa, Can., 8; New York, N. Y., 8; Philadelphia, Pa., 7; Portland, Me., 7; Antigonish, Can., 7; Huntington, Can., 7; Quebec, Can., 7; Knoxville, Tenn., 6; Washington, D. C., 6, Murray Bay, Can., 6; Tadousac, Can., 6; Portsmouth, N. H., 5; Rivière du Loup, Can., 5; Cambridge, Mass., 4; St. John, N. B., 4; Metis, Can., 4; St. Pauls Bay, Can., 4; Wolfsboró, N. H., 4; Baltimore, Md., 4; Savannah, Ga., 4; Rochester, N. Y., 4; Whiteville, Va., 4; Buffalo, N. Y., 3; Richmond, Va., 3; Annapolis, Me., 3; Milledgeville, Ga., 3; Bald Mountains, Va., 3; Mount Pleasant, Ky., 3; Laconia, N. H., 3; New Haven, Conn., 3; Hamilton, Can., 3.

2. Places of two epicenters each[1]).

Albington, Va.; Addison, N. Y.; Antrim, Pa.; Augusta, Ga.; Augusta, Me.; Beadsburg, Can.; Bloomfield, Conn.; Burlington, Pa.; Catlettsburg, Ky.; Clinton, Ga.; Columbia, S. C.; Eastport, Me.; Father Point; Can.; Frederick, Md.; Garretsville, O.; Hartford, Conn.; Keene, N. H.; Lancaster, N. H.; Lexington, Ky.; Louisville, Ky.; Macon, Ga.; Manchester, Ky.; Murphy, S. C.; New Albany, Ind.; Newport, R. I.; Ogdensburg, N. Y.; Onondaga, N. Y.; Palmer, Mass.; Point Judith, R. I.; St. André, Can.; St. Martin, Can.; Salem, Mass.; Schenectady, N. Y.; Trenton, N. J.; Wilmington, N. C.

3. Places of one epicenter each.

Accomac, Md.; Aiken, S. C.; Albany, S. Y.; Amsterdam, N. Y.; Ashtabula, O.; Ashland, Va.; Auburn, N. Y.; Bathurst, N. B.; Belfast, Me.; Bridgetown, N. S.; Brooklyn, N. Y.; Burlington, Vt.; Caledonia, N. Y.; Camden, Me.; Campbelford, Can.; Cape Breton, Isle, Can.; Cape Lookout, N, C.; Cayuga Lake, N. Y.; Central Harbor, N. H.; Ceres, N. Y.; Charlotte, Va.; Chaumont, N. Y; Cleveland, O.; Cincinnati, O.; Colburne, Can.; Colchester, Conn.; Coos, N. H.; Cornish, Me. (or N. H.?) Cornwall, Can.; Digby, N. S.; Dorchester, Mass.; Dover, N. H.; East Greenwich, R. I.; Elmira, N. Y.; Erie, Pa.; Fairfield, Me.; Farmville, Va.; Fincastle, Va.; Flushing, N. Y.; Franklin, Tenn.; Fredericton, N. B.; French Mountain, N. Y.; Glens Falls N. Y.; Goshen, N. Y.; Greensboro', N. C.; Groton, N. H.; Guilford, Conn.; Halifax, N. S.; Hawkesbury, Can.; Henniker, N. Y.; Hopkinton, Mass.; Huevelton, N. Y.; Huntingdon, Can.; Isle Jesus, Can.; Kamouraska, Can.; Lebanon, N. H.; Lincolnville, Me.; Lisbon, N. H.;

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[1]) An asterisk indicates that the place is not plotted on the map of plate 1.

Little Falls, N. Y.; Lockport, N. Y.; Louisa, Va.; Lynchburg, Va.; Machias, Me.; Madison, Me.; Maysville, Ky.; Meridith, N. H.; Milford, Mass.; Morristown, N. J.; Mount Morris, N. Y.; Mount Pleasant, Ky. (or Tenn.?) Mount Vernon, Ky.; Nashua, N. H.; New Bedford, Mass.; Newbern, N. C.; Newcastle, Pa.; Newcastle, Can.; New London, Conn.; New Market, N. H.; Newton, Mass.; Niagara, Falls, N. Y.; Norfolk, Va.; Northampton, Mass.; North Salem, N. H.; Ogreeta, Va.; Olean, N. Y.; Oshawa, Can.; Oxford, N. C.; Peekskill, N. Y.; Peterboro, N. H.; Petersburg, Va.; Plymouth, Mass.; Port Jefferson, N. Y.; Potsdam, N. Y.; Princeton, N. J.; Raleigh, N. C.; Reading, Mass.; Rice Lake, Can.; Richmond, Ky; Richmond, Me.; Richmond Can.; Rothesay, Can; Rockland, Me.; Roxbury, Mass.; Rye, Me.; St. Louise, Can.; St. Paul de la Valtrie, Can.; Sandersville, Ga.; Sandy Hook, N. J.; Shelburne, N. S.; Snow Hill, N. C.; Springfield, Mass.; Staten Island, N. J.; Sydney, Can.; Toms River, N. J.; Turners Falls, Mass.; Vienna, Can., Villanow, N. C.; Welland Canal, Can.; Westfield, Mass.; Weston, Mass.; Winchester, Va.; Windsor, Conn.; Winnsboro, S. C.; Woburn, Mass., Woodstock, Va.; Zanesville, O.; Yarmouth, N. S.

Distribution of other epicenters not definitely located.

Northern New York State and Canada, 13; Northern New York State, 3; Livingston County, N. Y., 1; New England, 46; Nova Scotia, 1; Maine and New Brunswick, 5; New Brunswick, 1; Lower St. Lawrence Valley, 7; Northeast of Green Mts., 1; New Hampshire and Canada, 1. New Hampshire, 5; Southern New Hampshire, 2; Massachusetts and New Hampshire, 1; Massachusetts, 1; Northeastern Massachusetts, 1; Middlesex County, Mass, 1; Essex County, Mass. 1; Southeastern New England, 1; Massachusetts and Rhode Island, 1; Rhode Island, 1; Connecticut and Rhode Island, 1; Southwestern Corner of Massachusetts, 1; Columbia County, N. Y., 1; Lower Hudson River, 1; Long and Staten Islands, 1; Northern New Jersey, 1; New Jersey, 2; Southern New Jersey, 2; Lower Delaware, 1; Maryland, 2; Prince Georges County, Md., 1; Virginia, 5; James River, Va. 1; Yonah Mountains, 1; Blue Ridge Mountains, 1; Southern Alleghenies, 4; South Carolina, 10; Tuckermut, Mass. 1; Georgia, 5; Kentucky, 1; Tennessee, 1.

Contents.

IX.

The Geotectonic and Geodynamic Aspects of Calabria and Northeastern Sicily.

A Study in Orientation

by

William Herbert Hobbs.

With an introduction by the Count **de Montessus de Ballore.**

With plates III to XII and 3 figures in text.

Préface.

Dans l'espace de 25 à 30 années seulement s'est créée, pour ainsi dire presque de toutes pièces, une science nouvelle et autonome, celle des tremblements de terre, en un mot la séismologie, qui n'était guère jusqu'à *Mallet*, vers le milieu de XIX^{me} siècle, qu'une collection confuse de «*faits divers*», qu'on supposait en relation avec les phénomènes météorologiques et cosmiques les plus disparates. Le savant anglais a voulu, un des premiers, faire régner l'esprit scientifique dans ce fatras et il y a réussi en un certain degré par la simple introduction des mesures. C'est qu'en effet une science ne se constitue véritablement et n'acquiert de légitimes droits à ce titre qu'à partir du moment où elle plie les phénomènes à des mesures chiffrées, seules capables de conduire à des résultats dignes de foi et de permettre des conclusions solides. Les théories passent, les observations restent; tel est le secret du succès d'une évolution qui a rapidement suffi à faire passer la Séismologie au rang des plus importantes branches du savoir humain grâce à ses appareils spéciaux et à ses observatoires propres et parce qu'elle a la prétention justifiée de mettre les populations des pays instables dans une notable mesure à l'abri d'un des

plus redoutables fléaux de la Géophysique. Ses adeptes sont maintenant légion alors que naguère encore, en France, un Perrey passait pour un simple collectionneur de tremblements de terre dont il fallait excuser la curiosité.

Mais le brillant essor que la séismologie a pris sous nos yeux n'a pas été sans un grave danger qui aurait même pu sérieusement compromettre son avenir, au moins pour un temps: une pléiade de physiciens éminents s'est abattue sur elle et ils l'ont dotée d'admirables appareils, les séismographes, qui permettent d'annoncer à Rome un tremblement de terre du Japon ou de la Californie avant même que le télégraphe en ait apporté la nouvelle. Le principal résultat des travaux considérables entrepris dans cette voie surprenante a été la découverte des microséismes qui relient la séismologie à la météorologie et à la géodésie. Partant de l'infiniment grand, le tremblement de terre destructeur, on était, sans le vouloir, arrivé à l'infiniment petit des effets des mouvements des astres ou de l'atmosphère sur l'écorce terrestre en état presque constant de minuscules frémissements. Mais du haut de la tour d'ivoire de leurs observatoires les séismologues physiciens n'oubliaient qu'une chose, le véritable tremblement de terre dont les causes ne veulent décidément pas se plier au gré des pendules même les plus sensibles et les plus délicats.

Heureusement les géologues veillaient et, sans laisser leur attention s'écarter de l'écorce terrestre, ils cherchaient l'origine des macroséismes dans l'histoire du passé de la terre et dans ses vicissitudes actuelles toujours en puissance. Ils édifiaient ainsi lentement et modestement leur école en face de celle des physiciens, bien convaincus de trouver le but au bout de leur chemin. Mais il n'a pas fallu moins que le nom d'un *Suess* pour retenir quelques chercheurs dans cette voie, la seule vraiment féconde, et cependant quelles difficultés n'ont pas rencontrées ses continuateurs. Les séismologues les tenaient pour en marge de leur science et la plupart des géologues ne voyaient guère dans les tremblements de terre que des phénomènes secondaires et sans intérêt devant la grandiose reconstitution de la vie du globe à laquelle ils consacraient tous leurs efforts. Mais lentement les observations se sont tellement accumulées qu'il a fallu finir par se rendre à l'évidence: les tremblements de terre constituent justement un des phénomènes les plus constants des processus géologiques et orogéniques et ils sont le plus sûr critérium au moyen duquel on peut diagnostiquer la vitalité actuelle des actions auxquelles la terre doit sa physionomie d'aujourd'hui et tend à acquérir ses traits de

demain. Là où il ne tremble pas, l'écorce morte reste en butte aux seules actions destructives de l'érosion et de la dénudation, là au contraire où il tremble, elle est vivante encore et prépare le renouveau de sa structure géographique.

Ainsi la séismologie s'est nettement divisée en deux branches rivales qui se devant, cela va sans dire, un mutuel appui, ne se le marchanderont plus, tout en continuant de suivre des voies divergentes jusqu'au jour, sans doute prochain, où elles se compléteront l'une l'autre dans un brillant concours.

En même temps que s'opérait cette double évolution, l'idée que l'on se faisait d'un tremblement de terre, subissait aussi la sienne. Pour l'école ancienne de *Mallet*, et jusqu'à nos jours, c'était un point géométrique, l'épicentre, comme conséquence de la théorie volcanique des mouvements du sol et de la croyance générale à l'existence du noyau fluide interne terrestre. Cette approximation, toute idéale, était par trop grossière; aussi les méthodes pour déterminer la profondeur de ce point fictif ont-elles toutes fait faillite successivement malgré l'ingéniosité de leurs auteurs. Il en a été de même pour la vitesse de propagation des ondes séismiques à courte distance, cela se comprend sans peine puisqu'elles émanent simultanément de tous les points d'un solide de grandes dimensions. On restait ainsi complétement désarmé devant le problème séismique, puisqu'en réalité on ne pouvait même pas fixer le point d'où émane un tremblement de terre. La notion d'épicentre a donc dû disparaître depuis que *Suess* et ses continuateurs ont montré avec la plus grande évidence que les séismes résultent du mouvement d'ensemble d'une portion plus ou moins notable de l'écorce, en un mot d'une des pièces de la marqueterie terrestre suivant l'heureuse expression de de Lapparent. Il est probable dans ces conditions que les tremblements de terre se produisent bien moins profondément que ne faisaient admettre les résultat numériques généralement obtenus et oscillant entre 25 et 200 kilomètres et plus. On ne peut plus considérer un tremblement de terre comme une sorte d'explosion en un point idéalement géométrique et strictement limité, ce qui fait du même comp disparaître les actions hypothétiques des gaz d'un magma général non moins hypothétique. La notion d'épicentre a cependant rendu de grands services puisque, mentalement réduite à sa juste valeur et à la condition d'avoir été appliqué à de très grands nombres, elle a permis d'arriver à la connaissance des lois de répartition de l'activité séismique à la surface du globe. Maintenant cette étape est franchie et pour l'étude particulière d'un

tremblement de terre il ne s'agira plus, dans la plupart des cas, du mouvement en un point d'un accident géologique, ni même de tout l'accident, mais bien d'une perturbation dans la position même d'un compartiment tout entier et par contrecoup de ses voisins, nouvelle conception dont M^r^ *Hobbs*, ainsi qu'on va le voir plus loin, est un des révélateurs.

Il ne manque pas d'analogie entre cette manière de voir et les lignes épifocales d'*Harboe.* Partant de cette idée très juste que les points d'une surface ébranlée, où le mouvement séismique a été observé en un même instant, sont également distants de l'accident géologique dont un changement d'équilibre a causé un tremblement de terre ou en a accompagné la production, l'un et l'autre phénomène pouvant d'ailleurs résulter au même titre d'un effort tectonique ou orogénique, *Harboe* a déduit une construction géométrique simple de la projection sur le sol de l'accident géologique à rôle séismogénique et situé à une plus ou moins grande profondeur, du reste inconnue. Malheureusement l'on ne peut compter sur un nombre suffisant d'exactes déterminations de temps, de sorte que la détermination ainsi faite des lignes épifocales n'a, en fin de compte, abouti qu'à tracer sur les cartes que des lignes compliquées et, ce qui est beaucoup plus grave, sans aucune relation apparente avec les traits géologiques connus de la surface. Le rôle séismogénique des lignes épifocales ainsi obtenues est donc de tout point inadmissible. Si, au contraire, les temps étaient exactement mesurés, les lignes épifocales feraient connaître les contours du compartiment terrestre mis en mouvement.

Indépendamment de la méthode d'*Harboe* dont l'insuccès ne tient qu'à l'emploi de données insuffisamment connues du temps, M^r^ *Hobbs* montre sans idée préconçue et par la seule observation de la manière dont se répartissent sur le terrain les dommages causés par les grands tremblements de terre, que les grands tremblements de terre dépensent presque exclusivement leur énergie le long de certaines lignes fixes de la région bouleversée. Ce sont les lignes épifocales d'*Harboe* pour ainsi dire matérialisées à la surface et directement vues en mouvement sans l'intermédiaire de l'observation délicate d'un élément accessoire, le temps. Or ces lignes de destruction exclusive, toujours les mêmes pour les divers tremblements de terre d'un même pays, correspondent trait pour trait aux dislocations et aux lignes structurales de la topographie et de la géologie de la région dévastée. Tel est le résultat concret du travail de M^r^ *Hobbs*

sur les tremblements de terre des Calabres et de la Sicile orientale. On acceptera donc sans difficulté l'exactitude de la conclusion du géologue américain, à savoir que les tremblements de terre résultent des efforts de réajustement des blocs de la marquetrie terrestre qui tendent à reprendre leur état d'équilibre rompu par le jeu des forces géologiques. C'est en petit pour un pays particulier ce qui se réalise au sein des grandes zones à tremblements de terre, ou géosynclinaux, pour l'ensemble de la surface terrestre et Mr *Hobbs* a eu le mérite de concrétiser par la pure observation ces voies nouvelles de la séismologie géologique.

Dès maintenant l'épicentre se réduira à l'emploi d'une expression commode dont l'inexactitude réelle ne fera plus illusion à personne et les relations des grands tremblements de terre prendront un tour purement géologique, ce que vient tout dernièrement de faire indépendamment de son côté, Mr *Tarr*, un compatriote de Mr *Hobbs*, pour le tremblement de terre de septembre 1899 dans la baie d'Yakutat (Alaska) non loin du fameux mont Saint Elie. On s'occupera surtout de déterminer quel compartiment terrestre a bougé, dans quel sens relatif — vers le haut ou vers le bas —, quels autres compartiments voisins ont eu par contre-coup leur équilibre rompu et enfin quelles modifications de relief ont été la conséquence du phénomène séismique dès lors considéré comme purement orotectonique. Ainsi l'idée d'*Harboe* prend corps et l'on voit que l'avenir de la séismologie, quant à la solution de ses problèmes fondamentaux, réside dans son étroite union avec la géologie, ce qui confirme l'idée que les grandes découvertes se font souvent sur les frontières mutuelles des sciences. Il reste encore, malgré tout, de brillantes espérances aux séismologues physiciens qui ont surtout à travailler sur les «*Marches*» de la météorologie et de la géodésie, en se réservant les incessants et minuscules frémissements de l'écorce terrestre ainsi que l'étude du mouvement séismique considéré en lui-même au point de vue mécanique.

En Calabre, Mr *Hobbs* n'a fait qu'interroger les faits; c'est le plus bel éloge qu'on puisse faire de son étude de tectonique séismologique: les théories passent, les observations restent.

Abbeville, le 29. Mai 1906.

de Montessus de Ballore.

General Introduction.

Peculiar outlines of Southern Italy. The province of Calabria, and in fact the entire Italian peninsula south of Naples with the island of Sicily, offers a interesting problem in lineamental orientation. The coast on the west and south is formed of bold bluffs stretching for long distances in essentially rectilinear courses to prominent headlands, where a new direction is taken, so that the several straight elements compose a series of most striking zigzags. On the east the mountains recede more from the coast, but the same tendency to exhibit rectilinear stretches of shore line is apparent; and, as regards the peninsula as a whole, a rectangular set of lineaments appears with the one series directed to the northeast, and the other to the northwest. *Charles Darwin*[1]) long ago called attention to the possible significance of these features, and more recently *Green*[2]) has reverted to it. The northeasterly direction is well brought out by the eastern Sicilian coast line and by the nearly parallel train of volcanoes, which, beginning with the Linosa includes Lipari, Panaria, and Stromboli. This direction is about N 35° E. The nearly perpendicular direction appears in the boundaries of the Gulf of Taranto, the Calabrian Appenines, and in the volcanic line, Tolfa—Albano—Vesuvius.

Wherever the mountains approach the sea in Calabria, they rise from it in a series of *pianos* or terraces, the number of which bears some relation to the altitude of the ranges[3]).

Meissonier has likened these terraces to the "Parallel Roads" of Scotland. They are characteristic of nearly the entire coast. On the western or Tyrrhenian coast, four distinct series of terraces have been recognized, while on the gentler slopes which border the Ionian coast, only two have been made out. Similar terraces are characteristic also of the borders of the broad valley of the Crati, where they are prominently revealed[4]), and they have also been shown to char-

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1) *Charles Darwin,* Geological observations.

2) *William Lowthian Green,* Vestiges of a molten globe. pt. II, pp. 144—155, also appendix.

3) *M. Meissonier,* Observations sur la constitution géologique de la Calabre etc., C. R. de l'Acad. Franc., vol. 46, 1858, pp. 1090—1093. *L. Burgerstein* und *F. Noë,* Geologische Beobachtungen im südlichen Calabrien. Sitzungsber. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., Bd. 81, 1880, Abt. I, pp. 155—156.

4) *E. Cortese,* Descrizione geologica della Calabria. Mem. desc. della Carta geologica d'Italia, vol. 9, 1895, p. 192, pl. 4.

acterize the walls to the south of the depression at Catanzaro — "Straits of Catanzaro".

Recent formation of the Mediterranean floor. The body of evidence which has been slowly gathered to show that in geologically very recent times, Europe was connected tó Africa, is of prime importance in connection with a study of the geologic history of Calabria. The discovery in Malta and Sicily of abundant remains of such distinctively African animals as the elephant, and hippopotamus, which were living together with the present southern European fauna, leaves no room for doubt of the former land connection of the two continents in question[1]).

In the caves near Palermo in Sicily the remains of elephants were found in such quantity that ship-loads were removed for the manufacture of lamp-black. Further evidence collected from Spain and Morocco when considered in connection with the common Lusitanian fauna of Southwestern Europe, the Barbary States, and the Canary Islands, militates strongly against the earlier connection having been by a narrow isthmus. Says *Wagner*[2]).

"The Mediterranean in respect to its natural history is less of a barrier between the north coast of Africa and Europe than is, on the other hand, the Sahara from the main mass of the African continent. From all evidences the Sahara was once flooded by the sea, by which the Barbary States were added to the islands of the Mediterranean".

The "Adventure Bank" of Admiral Smyth (The sunken Area of Virgil) together with the Skirki Bank constitutes an extended submarine plateau now joining Sicily to Africa. Above this table-land the flat Malta and Gozzo, separated from each other by deep fissures, and the still flatter Lampedusa; rise as the sole relics of the otherwise submerged floor which once connected the continents in this vicinity. Pantellaria, Linosa, and Ferdinandia are purely volcanic,

1) *Anca,* Note sur l'existence de *l'Elephas africanus* en Sicile. Bull. de la Soc. Géol. de France, vol. 18, 1860, pp. 90—91, 680 ff. — *Adams,* Notes of a naturalist in the Nile valley and Malta. Edinburgh, 1870, pp. IX and 295. — *Eduard Suess,* Über die einstige Verbindung Nordafrikas mit Südeuropa. Jahrb. d. k. k. geol. Reichsanst., vol. 13, 1863, pp. 1—5.

2) *A. Wagner,* Die geographische Verbreitung der Säugetiere. Abhandl. d. k. bayer. Akad. d. Wiss., II. Kl., Bd. 4, Abt. III, 1846, p. 10. See also the instructive maps of *Taramelli* and *Bellio,* Geografia e Geologia dell' Africa. Hoepli, Milan, 1890, 7 maps.

and have been subsequently built up upon the sunken basement. To the north of Sicily is the so-called "Tyrrhenian depression", a submerged land mass, from which only Sardinia, Corsica, and Elba project and upon which the volcanoes constituting the Eolian Islands have been elevated. Evidence is not entirely wanting that the Ionian sea has had a similar origin, and submarine eruptions have been recorded in connection with the quakings about its borders.

Dislocations in Southern Italy. We owe much of our best knowledge of Calabria to that little company of German geologists which visited the region in the early seventies, and wich included *Gerhardt vom Rath*, *Theodor Fuchs*, and *Eduard Suess*. *Vom Rath*, the experienced traveller and keen observer, has given us what is to-day the most fascinating and interpretive general description of the physiognomy of the region. Calabria properly begins at the lower valley of the Crati near Castrovillari, regarding which boundary *vom Rath's* clear and expressive language may well be quoted[1]):

"The Appenines end near Castrovillari. Suddenly the great limestone range drops down on wall-like precipices, though peaks rise almost at the southern margin to altitudes of more than 2200 meters (7218 feet). Seen from the south the precipice appears as a high extended mountain wall with sharp-angled pyramidal peaks stretching away to the eastward in the direction of Amendolea on the Gulf of Taranto",

The upper Crati valley *vom Rath* recognized as a great depressed fault block or *Graben* bounded on either hand by crystalline rocks of wholly different types. To the southwest of this is the fault valley of the Savuto. The striking table-structure of the greater part of the country already referred to here in describing its terraced shore lines, *vom Rath* has illustrated by the northern margin of the crystalline mass to the south of the "Straits of Catanzaro".

"From Tiriolo one sees the southern horizon outlined by broadly extended curving lofty terraces which rise higher toward the South".

This dropping down of the high plateaus of Calabria in a series of terraces at their margins, has not failed to strike every geologist

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1) *G. v. Rath,* Geognostisch-mineralogische Fragmente aus Italien. IV. Teil, X, Geognostisch-geographische Bemerkungen über Kalabrien. Zeitschr. d. deutsch. geolog. Gesellsch., vol. 25, 1873, pp. 150—209.

who has visited the country. *Fuchs*[1]) has given an important description of such terraces from the vicinity of Gerace:

"It has been already noticed that near Gerace in the nearer foot-hills toward the sea the individual members of the Pliocene lie at a much lower level than on the mountains surrounding the city, and the conclusion has been drawn that these foot-hills represent parts of the Pliocene plateau which have been dropped down. Should the facts actually be as stated, then it follows that great faults lie between the foot-hills and the mountains of the city of Gerace; and one would expect in ascending along the new road to find traces of such faults.

This assumption is actually confirmed and exposures along the road show an almost continuous series of faults and disturbances of every kind. Particularly noteworthy is it that one has *Zanclée* clay under his feet at the lower side of the city, while with further ascent after a series of great faults he suddenly encounters the Bryozoan Limestone again". (pp. 41—42).

There has been little difference of opinion among geologists regarding the important rôle played by block faults in bringing about the present relief of the province. Says *Suess*[2]).

"From Palermo to Messina, and from there to Cape Spartivento and to Capri, the Tyrrhenian sea is surrounded by lines of dislocation, and still further by way of the Cape of Circeo to Elba and Spezia the mountain system is broken off and dropped down. Under the Tyrrhenian Sea lies the tectonic axis of the Italian peninsula, which in its present condition represents only the projecting fragments of the ancient extended Tyrrhenian mountain mass".

In his great work[3]) he has recognized in the block-like masses of crystalline rock so characteristic of Calabria, the fragments of a once connecting land mass which included Sicily, Sardinia, and Corsica; these fragments being bounded by great displacements, the most profound of which surround the Tyrrhenian depresion, connect the volcanic islands within it, or go out from them toward the mainland and Sicily.

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[1]) *Th. Fuchs,* Geologische Studien in den Tertiärbildungen Süditaliens. Sitzungsber. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., Bd. 65, 1872, I. Abt. Heft 6, pp. 7—56.

[2]) *Ed. Suess,* Über den Bau der italienischen Halbinsel. Sitzungsber. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., Bd. 65, 1872, I. Abt., pp. 1—5.

[3]) Antlitz der Erde, Bd. I, pp. 110—114.

Cortese's excellent monograph[1]) upon Calabria is the official description of the Italian Geologic Committee and the most complete work upon the geology of the province. Speaking of the tectonic structure of the province, *Cortese* says:

"In Calabria we find many great lines of most important fractures, besides numerous secondary fractures which generally accompany the larger ones. These have influenced much the form and constitution of the region . . . .

Since Calabria is then a fragment of a larger continent (The Tyrrhenide) to which belong also Sardinia, Corsica, the Apuan Alps, and the minor masses of Peloro, Argentaro, Elba, etc.; it is natural that the breaking-up of so large a mass with the disappearance of the greater part, would not have been possible without fundamental fractures which have caused the separation of the several parts and are connected with the destruction by depression of the larger part. In any case, the Calabrian fractures have the merit of being evident (less, naturally, then we could wish to see), and hence are easily indicated and explained".

Of the six more important lines of dislocation in Calabria which have been given detailed descriptions by *Cortese*, that of the Straits of Messina follows the rectilinear eastern coast line of Sicily from Etna to the vicinity of Messina, then the abrupt Calabrian coast line to Palmi[2]). From there it runs to the east of the crystalline mass of Cape Vaticano through the communes of Rosarno, Mileto, Maierato, and near Filadelfia and Cortali to Caraffa[3]). East of Catanzaro this dislocation is described as following a zigzag course past Cropani, Petilia Policastro, S. Nicola dell' alto, and Ciro to Punta d'Alice (see plate 2, volcanotectonic map).

The fault of the lower valley of the Crati is believed by *Cortese* to be connected with one which crosses Sicily from the direction of Pantellaria as a line of warm and sulphurous springs. Entering Calabria near Guardia Piemontese it follows the western and northern walls of the Pliocene bay occupied by the Crati (*Cortese's* fault 2). A third major fault of *Cortese* follows the straight upper

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1) *E. Cortese,* Descrizione geologica della Calabria. Mem. desc. della Carta geolog. d' Italia, vol. 9, 1895, pp. XXVII and 310, map and plates.

2) The sea is characterized by profound depths immediately off shore in this vicinity.

3) *E. Cortese,* L' interruzione dell' Appennino al sud di Catanzaro. Boll. d. R. Com. Geol. d' Italia, vol. 14, 1883, pp. 166—178, map and plate.

Crati valley in a direction a little west of north (Nicastro to Castrovillari). The fault of the Straits of Catanzaro is almost perfectly straight and strikingly marked out by high rock walls which are the boundaries of formations. In *Cortese's* words:[1])

"This second fault running from Cape Suvero to the point of Staletti, is perfectly straight and passes below Maida, past Cortale, and near Squillace."

The other marked contraction of the Calabrian peninsula to the south of Cape Vaticano is the course of a fault suggested both by the topography and the areal geology, and confirmed by field work. This fault, according to *Cortese*, enters Calabria a little to the North of Gioia Tauro, passes through the higher country to the east along a zone where the granitic back-bone is replaced by Pliocene deposits (near Mammola, Grotteria, and Gerace). Another fault which coincides with the precipitous southwestern bluff-line of Cape Vaticano, enters the same gorge by way of Nicotera and is apparently continued eastward on the same or a near-lying parallel plane to the last mentioned. The last of the six faults specially mentioned by *Cortese* goes out from the crater of Etna and forms the southern limit of the Calabrian peninsula from Melito to Cape Spartivento.

The Triassic area to the northward of the valley of the Crati is included in the area which has been studied by *Böse* and *De Lorenzo*[2]). Of it they say:

"In this part we find mighty domes and basins which consist of firm limestones and dolomites. These domes and basins are cut in various directions by faults. Often the domes are split into quite small blocks such as we have seen at Nemoli, Saracena, and between Lungro and Tavolara; the basins are ruptured by radial and concentric fractures, and likewise divided into larger or smaller blocks. In the case of both domes and basins the commonest kind of faulting is the steep-like dropping down, overthrusts being very rare and indeed only apparent because a block before the elevation, or at the beginning of it, either sank or was elevated on vertical planes; and, when by further elevation the faults took an inclined position, they resemble closely an overthrust . . . . ,"

The larger number of other papers treating of Calabrian geology,

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[1]) *E. Cortese,* Boll. d. R. Com. Geol. d' Italia, vol. 14, 1883, p. 135.

[2]) *E. Böse* und *G. de Lorenzo,* Geologische Beobachtungen in der südlichen Basilicata und dem nördlichen Calabrien. Jahrb. d. k. k. geol. Reichsanst., Bd. 46 1896, pp. 235—268.

are either devoted specially to the seismic phenomena or to the stratigraphy, paleontology, or petrography.

Baldacci, who has written the principal report upon Sicily[1]), has recognized the great fault of the Straits of Messina, as he does also numerous other faults of small extent and displacement; but he does not ascribe much importance to them in the fashioning of the island. Of very special interest, however, is the train of mud volcanoes — *volcani di fango* — which runs in a nearly exact straiht line entirely across the island. Entering near Siculiana to the west of Girgenti, it passes south of Grotte and Caltanisetta to Paternò on the flank of Etna (direction N 77° E), and has played an important rôle in the formation of the sulphur deposits of the island. There are also other trains of such vapor vents both in Sicily and in the Appenines which would well repay a study of their distribution and arrangement.

Seismicity of Calabria an indication that its tectonic movements are not yet completed. The displacements upon the borders of Calabria and within its territory, are still going on; and their sensible manifestations have made Calabria, and only less the Italian peninsula and southern Europe, the classic region for the study of seismic action. Calabria itself holds, however, a most undesired preeminence in this regard. It is not only the part of the European continent which has been most frequently shaken within historic time, but, if we except the great Lisbon earthquake of 1755, it has been subjected to the most powerful shocks. It is but another indication of the newness of the architecture of the peninsula of Italy, that it is likewise the world's classic region for the study of present day volcanic action.

Purposes in view in conducting the present inquiry. The facts above recited showing that Calabria is constituted of a *marqueterie* of orographic blocks separated by planes of displacement and which sustain relations of shape, position, and orientation not only to their neighbors upon the peninsula, but to the remnants of the ancient Tyrrhenian continent, make Southern Italy an especially favorable district for the study of the orientation of fracture planes, whether exposed for examination as joints, or on the larger scale as well determined faults or as striking rectilinear earth features — *lineaments*[2]). Two additional

[1]) *L. Baldacci,* Descrizione geologica dell' Isola di Sicilia. Mem. descr. della Carta geol. d' Italia, vol. 1, 1866, pp. XXXI and 403, map and 11 plates.

[2]) See, lineaments of the Atlantic Border Region. Bull. Geol. Soc. Am., vol. 15, 1904, pp. 483—506, pls. 45—47.

advantages which Calabria offers for such a study which it would be difficult to duplicate elsewhere, are furnished by its numerous active and recently extinct volcanoes — whose distribution is most interesting — and by its intense seismicity [1]).

For the essentially right lines which join three or more volcanic vents, the term *volcanitectonic lines* — geotectonic lines indicated in the alignment of volcanic vents — has here been used.

The advantages offered by Calabria for studies in orientation have been often in the mind of the writer; so that when in 1905 the desired opportunity came of again visiting the Italian peninsula, a study of its joint system was contemplated. That the most disastrous earthquake of the province for more than a century should have occurred while the writer was en route to study its geology, was for him a most opportune circumstance; for it has made it possible to subject to investigation the geographic aspects of this great seismic disturbance.

Acknowledgments. As the present inquiry has been conducted throughout in foreign territory, it is a pleasure to record the uniform courtesy which has been shown the author by Italians of all classes. In the field his studies were greatly facilitated by Sig. *Giuseppe Allegretti* of the telegraph office at Bari; by Sig. *Oreste Daffinà*, correspondent at Monteleone of „*Il Secolo*" of Milan and agent of the *Agenzia Stefani*; and by Professor *Bernardi*, the President of the Royal Lyceum at Monteleone. For the privilege of making a tracing from a valuable map upon which communes damaged by the recent earthquakes had been entered, the author's thanks are especially due to General *Ferrario* and his Chief of Staff, Colonel *Riccardi*, in charge of the work of succor in the district affected. To the officials of the many excellent scientific libraries at Rome, and especially those of the Italian Geographical Society, the Royal Academy of Science (*Accademia dei Lincei*), the Royal Geological Committee, and the Central Office for meteorology and geodynamics, he is indebted for a much esteemed privilege of using maps and books with all the freedom accorded to their own members. To Professors *Pallazzo, Agamennone, Baldacci,* and *Monti* special acknowledgment is also due.

Of the value to him of the sympathetic interest manifested almost

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1) Seismicity is here used to imply both frequency and intensity of seismic action. See *De Montessus de Ballore,* Relation entre le relief et la sismicité C. R. de l'Acad. Franc., vol. 120, 1895, pp. 1183—1187.

throughout the investigation by Professor *Eduard Suess* and the Count *de Montessus de Ballore*, the author would make grateful recognition. Major *de Montessus* has kindly volunteered to compute the seismicity of the provinces studied by his method of epicenters, and the results appear upon a valuable map which he has contributed to the work (plate IV).

The grand lineaments of Calabria and northeastern Sicily.

Distribution of geological formations. As already pointed out, the great limestone backbone of Italy — the Appenine chain — terminates abruptly upon the borders of the valley of the lower Crati; where, in a geological, though not in a political sense, the Calabrian province begins. South of this margin there are no ranges in any proper sense, but rather a number of broad areas of high terraced table-land separated by wide depressed valleys. The formations which constitute the higher mountain country, are throughout crystalline, and include granite, and in smaller quantity other igneous rocks, as well as numerous types of crystalline schist and gneiss of undetermined age. The material found within the depressed areas, on the other hand, is in contrast the slightly indurated formations of Tertiary, Quaternary, and Recent age. Both *vom Rath*[1]) and *Suess*[2]) have ably set forth the geognostic features of the several fragments of the crystalline terranes. On the map of plate 2 the colored areas have been entered from the map of the same scale by the Italian Geological Committee (a map upon a scale of 1 : 500000, reduced from a scale of 1:50000), and have been outlined for the author by Sig. *Amadeo Aureli*, the Chief Draughtsman of the office. The granite and other igneous rocks have been represented by a single color, the several types of crystalline schists by a second color, the gneiss mass of the Aspromonte and Peloritani by a third, the Trias and Lias of the northern border by a fourth, while the Tertiary and later formations have been left uncolored. The geological boundaries have been transferred with great care, and the modifications from the official map through the combination of for-

1) *G. v. Rath,* Geognostisch-geographische Bemerkungen über Calabrien. Zeitschr. d. deutsch. geol. Gesell., Bd. 25, 1873, pp. 150—209.

2) *Ed. Suess,* Über den Bau der italienischen Halbinsel. Sitzungsber. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., Bd. 65, 1872, I. Abt., pp. 1—5. Also Antlitz der Erde, Bd. I, pp. 110—114.

mations, possess for the geotectonic and especially the seismotectonic study the advantages of greater simplicity and of sharply differentiating the relatively hard, elastic, and elevated terranes from the soft and inelastic low-lying ones. The uncolored areas are, further, those of the denser population, a fact which should not be lost sight of. Largely because in the early settlement of the country difficultly accessible positions were selected for their easier defense against enemies, and, further, because the chief products of the region are the fruit of the olive, fig, and vine; cities and villages are for the most part located either along the coast or upon the steep slopes which rise above the plains — in either case at the margins of the crystalline masses.

The narrow neck of land which separates the Gulf of S. Eufemia from the Gulf of Squillace, the "Straits of Catanzaro", devides Northern from Southern Calabria. Geologically, the former is bounded upon the north by the fault-wall which terminates the Appenine chain (see plate III, V, Fig. 1).

The center of Northern Calabria is occupied by the Sila, a nearly rectangular mass of crystalline rock oriented in conformity with the meridians and parallels, and thus offering in respect to form, orientation, and constitution a striking resemblance to Sardinia. The Sila mass is divided by a nearly rectilinear diagonal into a northeastern half composed of granite and a southwestern one made up of various types of schist and gneiss. In shape and orientation, therefore, this northeastern half much resembles the crystalline mass of the island of Corsica.

A second area, but here without granite and mainly composed of schist, which is known as the Cocuzzo mass, borders the western coast of Northern Calabria and is separated from most of the Sila by the deep trough of the Crati. At the south end, howewer, it is connected to the Sila mass by crystalline phyllite.

In Southern Calabria are found two masses in many respects similar to those of the Sila and Cocuzzo, only that they are here reversed and, further, are both oriented in a diagonal direction. These are the Pecoraro and the double Cape Vaticano-Filadelfia masses, which are in part divided by the broad Mesima trough, as are the Sila and Cocuzzo by the Crati. The eastern mass is here likewise of granite, while the western composite mass is more largely of schistose rocks. In the extreme south of the peninsula is found a fifth mass — the Aspromonte, largely composed of gneiss, but with

a southern fringe of schist. To the west of the Aspromonte and across the Straits of Messina, is the mass of the Peloritani composed of the same type of gneiss, a mass which has been isolated through the depression of the Straits of Messina. A third, and an extremely small, area of the Aspromonte gneiss forms the remarkable peninsula of Milazzo to the northwest of the Peloritani.

Description of the grander lineaments. If the distribution of the crystalline rock masses in Calabria be remarkable, their boundaries are certainly not less striking. Whether they be coast lines or the borders of depressed areas, they are alike in their straightness for long distances. With few, if any, exceptions they are topographic as well as geologic boundaries, and as such they merit our attention as probable geotectonic lines, or lineaments. The greater number of these lineaments, which are indicated in plate V, Fig. 1 and numbered from 1 to 29, are directed either near to the meridian or parallel, or in diagonal directions. Perhaps the most striking of all, outlines the southeastern coast of Sicily from Taormina to Messina (*19*, N 32° E) — *Cortese*'s fault of the Straits of Messina. This direction is nearly parallel to the fault-wall at the southern termination of the Appenines (*6*, N 38° E), included in *Cortese*'s fault No. 2. The Bagnara-Nicotera coast line (*23*, N 21° E) is a line of sea bluffs bordered by profound depths, and is included in fault No. 1 of *Cortese*. Another portion of the same fault is the Bagnara-Scilla coast line (*28*, N 83° E) of similar character, whose direction is continued eastward as a part of the northern margin of the Aspromonte, and westward as the northern coast line of Sicily and the southern limit of the small Milazzo mass of Aspromonte gneiss. No less pronounced is the lineament (*27*, N 76° E) which separates schist from gneiss in the mass of the Aspromonte and passes westward across the straits along the northern border of the Etna block. Almost exactly parallel to this line is the train of mud vulcanoes (N 77° E) which starting at Paternò on the southwestern flank of Etna extends westward entirely across Sicily passing through the sulphur district to Siculiana. Almost exactly east-west is the direction of the abrupt southern termination of Calabria (*26*), *Cortese*'s fault No. 6. The southern border of the Sila and Cocuzzo (*10*) is marked by irregularities and cannot be accurately fixed in its general direction though nearly equatorial.

Two striking lineaments closely approaching the meridian in their direction are the eastern and western borders of the Sila mass (*13*

and *29*). From the latter, the steep eastern wall of the Crati valley, the Sila rises in a series of terraces as already explained. To these the long eastern border of the Aspromonte is parallel (*14*) and to the north this line is the eastern border of the granite which constitutes the Cape Vaticano mass. The western boundary of the Aspromonte (*20*) is somewhat more ragged in its outline owing to the heavy superficial Miocene, Pliocene, and Quaternary deposits — the work of the *fiumare* or *torrenti* so active in this region. Hardly less striking are the walls bounding the Cocuzzo (*11* and *12*), one of which is the western margin of the Crati valley. The Belvedere-Cape Bonifati coast line of bluffs (*2*) is directed more to the west of north (N 14° W).

A parallel, or nearly parallel, series of strong lineaments is oriented N 46° W and given direction by the long contact of granite and schist which traverses the diagonal of the Sila mass. Extended across the Crati valley, the prolongation of this lineament outlines, first, the northeastern margin of the Cocuzzo mass; and, farther, the contact of Triassic and Eocene deposits. Line 5 of the series is within the Sila mass for a long distance the approximate contact of two well differentiated types of schist and corresponds to the southward closing in of the walls upon the Crati valley. It further forms a sharp offset in the coast line at the headland of Cape Bonifati. Lineaments *8* (N 37° W) and *9* (N 63° W) make up the remarkable southern wall to the Straits of Catanzaro and have already been describd as faults by *Cortese*.

The quadrilateral granite block of Cape Vaticano is outlined seaward by three sharp and remarkably straight lines of bluffs — the lineaments *15* (N 83° W), *16* (N 48° W), and *17* (N 63° E). Extended eastward the first mentioned or northern coast line, separates the main Pecoraro mass of biotite granite from the small tonalite mass about Gasperina. The southwestward coast line (*16*) similarly extended eastward from Nicotera to the Marina di Giojosa passes through a gorge occupied by Miocene deposits which separates the larger Pecoraro mass from a smaller detached area of the same granite. This corresponds to *Cortese's* fault No. 5. The western entrance to the Straits of Catanzaro is occupied by Quaternary deposits, but the margin of the Filadelfia mass of mica schist, gneiss, and garnetiferous schist (*18*, N 52° E), continued southwestward corresponds to the northwestern border of the Peloritani mass of gneiss, and continues on the western border of the Etna block — a

line of much significance in the seismic history of the Messina province. Lines *21*, *22*, and *6* are volcanotectonic lines, and line *25*, the Volcano-Milazzo line, may also be so regarded.

The joint system.

Objects and methods of investigation. The main purposes in view in making examination of the joints have been to determine: 1. whether there is a common orientation of the joints throughout the region studied; 2. whether this system, or systems, are as regards orientation independent of the nature of the rock; and, 3. whether relations of orientation connect the system, or systems, with known lines of dislocation, with volcanotectonic lines, with prominent lineaments, or with other tectonic lines however revealed.

That a common orientation within an single system might be expected has been foreshadowed by the now classical studies of *John Phillips*[1]) in Yorkshire, England; of *Samuel Haughton*[2]) in county Waterford, Ireland,; and by *Robert Harkness*[3]) in county Cork, Ireland; as well as by the writer's later studies in New England[4]).

The plan of the study was to measure the strike of the steep and nearly vertical joints at each of a number of widely separated and well distributed localities, and in rocks as different as possible. Owing to the fringe of the Tertiary to Recent torrential deposits which follow the coast line, and at the same time the only railraod

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1) *John Phillips,* Observations made in the neighbourhood of Ferrybridge in the years 1826—1828. Phil. Mag. and Ann. Phil., 2nd. Ser., vol. 4, 1828, pp. 401—409.

2) *Samuel Haughton,* On the physical structure of the Old Red Sandstone of the county of Waterford, considered with relation to cleavage, joint surfaces, and faults. Trans. Roy. Soc. Lond., vol. 148, 1858, pp. 333—348. See also by the same author, On the joint systems of Ireland and Cornwall, and their mechanical origin. ibid., vol. 154, 1864, pp. 393—411.

3) *Robert H. Harkness,* On the jointings in the Carboniferous and Devonian rocks in the district around Cork; and on the dolomites of the same district. Quart. Jour. Geol. Soc. Lond., vol. 15, 1859, pp. 86—104.

4) Tectonic geography of Southwestern New England and Southeastern New York. Bull. Geol. Soc. Am., vol. 15, 1903, pp. 554—556. The correlation of fracture systems and the evidences for planetary dislocations within the earth's crust. Trans. Wis. Acad. Sci. etc., vol. 15, pp. 15—29 (separates issued August, 1905 in advance of general publication).

that gives access to the country; it was nearly always found necessary to go some miles inland and into higher altitudes before satisfactory observations could be made.

Localities examined and the rock types found at each. The 553 measurements which have been made are distributed among eight stations as follows: 1. the western slope of the Cocuzzo mass between Cosenza and Paola (nearest to S. Fili) where various schists are found in outcrop (117 observations); 2. Rossano on the Gulf of Taranto in the massive red granite which gives the place its name (153 observations); 3. the vicinity of Catanzaro on the Gulf of Squillace, where the rock is a different type of granite with crystalline schists (45 observations); 4. Nicastro to the northeast of the Gulf of S. Eufemia in chlorite schist (38 observations); 5. Aiello and vicinity, where the rock is limestone (52 observations); 6. vicinity of Monteleone in the mass of Cape Vaticano, where both granite and garnetiferous and mica schists are encountered (24 observations); 7. Gesso to the northwest of the Peloritani mass in Sicily (about ten miles northwest of Messina) where the rock is limestone (only 15 observations); and 8., the vicinity of Taormina on the southeastern border of the Peloritani mass, where the structures were measured both in limestone and in phyllitic slate (109 observations). The location of these stations has been indicated upon plate V, Fig. 1.

The readings of joint strikes were made with a Brunton aluminium compass having a needle two inches in length. The better to eliminate the danger of bias in making readings of the bearing of slightly warped planes, which can at best be determined only to the nearest five degrees, an arbitrary needle variation was set off upon the compass dial and the corrections subsequently made[1]). An entry was made in the note book for each joint plane whose strike was measured, and the data thus obtained subsequently tabulated and corrected as follows:

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1) The magnetic variation for the Calabrian province was afterwards kindly furnished by Professor *Palazzo,* the Director of the Central Office for Meteorology and Geodynamics at Rome, and is very nearly eight degrees west of the meridian. For October, 1905, it was determined to be as follows: at Reggio 8° 4′; Pizzo 7° 55′; Cosenza 7° 55′; Rossano 7° 42′; Catanzaro 7° 42′; Amantea 7° 54′.

Comparative table giving the bearings of observed joint planes measured in Calabria and Northeastern Sicily.

I. Easterly strikes.

San Fili (Cryst. Schists)	Rossano (Red Granite)	Catanzaro (Granite and Schists)	Nicastro (Chlorite slate)	Aiello (Limestone)	Monteleone (Granite, Schists and Garnet Schist)	Gesso (Limestone)	Taormina (Limestone and slate)	Composite (from the preceding)
—	—	—	—	—	—	1 E 1	—	1 E 1
3 E 3	—	—	—	3 E 5	3 E 3	3 E 1	3 E 3	*3 E 15*
8 E 15	8 E 1	—	8 E 2	8 E 10	8 E 3	—	8 E 5	**8 E 36**
—	—	—	11 E 1	11 E 1	—	—	11 E 1	11 E 3
13 E 6	13 E 3	—	13 E 1	—	13 E 2	—	—	*13 E 12*
15 E 1	—	—	15 E 4	15 E 1	—	—	—	15 E 6
18 E 4	18 E 4	—	—	—	—	—	—	18 E 8
23 E 6	23 E 3	—	—	23 E 5	23 E 1	23 E 1	23 E 7	**23 E 23**
28 E 1	28 E 2	—	28 E 1	—	28 E 1	28 E 1	28 E 2	28 E 8
—	31 E 10	—	—	—	—	—	31 E 2	*31 E 12*
33 E 6	33 E 4	—	—	—	—	—	33 E 8	*33 E 18*
38 E 6	38 E 19	—	—	—	—	—	38 E 4	*38 E 29*
—	41 E 1	—	—	—	—	—	41 E 2	41 E 3
43 E 3	43 E 20	—	—	43 E 1	—	—	43 E 2	**43 E 26**
—	45 E 3	—	—	—	—	—	45 E 3	45 E 6
48 E 8	48 E 10	48 E 1	—	—	—	48 E 1	—	*48 E 20*
51 E 1	51 E 2	—	—	—	—	—	—	51 E 3
53 E 8	53 E 20	53 E 1	—	—	—	53 E 1	53 E 9	**53 E 39**
—	56 E 1	—	—	—	—	—	—	56 E 1
58 E 1	58 E 7	58 E 1	58 E 1	—	—	—	—	*58 E 10*
—	61 E 1	—	—	—	—	—	—	61 E 1
63 E 2	63 E 5	—	—	—	—	—	63 E 3	*63 E 10*
68 E 1	—	—	68 E 1	—	—	—	—	68 E 2
—	73 E 1	—	—	—	73 E 1	—	73 E 1	73 E 3
78 E 1	—	—	—	—	—	—	78 E 8	*78 E 9*
—	81 E 5	81 E 14	—	81 E 1	81 E 3	—	—	**81 E 23**
83 E 1	—	—	83 E 2	83 E 1	—	—	—	83 E 4
85 E 1	—	—	—	—	—	—	85 E 7	85 E 8
—	—	—	—	—	—	—	88 E 2	88 E 2
75	112	17	13	25	14	6	69	331

Comparative table giving the bearings of observed joint planes measured in Calabria and Northeastern Sicily.

II. Westerly strikes.

San Fili (Cryst. Schists)	Rossano (Red Granite)	Catanzaro (Granite and Schists)	Nicastro (Chlorite slate)	Aiello (Limestone)	Monteleone (Granite, Schists and Garnet Schist)	Gesso (Limestone)	Taormina (Limestone and slate)	Composite (from the preceding)
2 W 1	—	—	2 W 1	2 W 8	—	—	2 W 4	*2 W 14*
7 W 6	7 W 1	7 W 6	7 W 2	7 W 7	—	7 W 1	7 W 5	**7 W 28**
12 W 1	—	—	12 W 1	—	—	—	—	12 W 2
17 W 2	17 W 1	17 W 1	17 W 1	—	—	—	17 W 4	*17 W 9*
—	—	19 W 2	—	—	—	—	—	19 W 2
22 W 2	22 W 1	—	22 W 5	—	—	—	—	*22 W 8*
27 W 1	27 W 1	—	27 W 2	—	—	—	—	27 W 4
32 W 4	—	32 W 1	32 W 1	—	—	—	32 W 1	*32 W 7*
—	37 W 3	37 W 2	37 W 3	—	37 W 2	—	37 W 2	*37 W 12*
—	—	—	—	—	—	—	39 W 6	39 W 6
—	—	42 W 1	—	—	42 W 1	42 W 1	42 W 5	42 W 8
45 W 2	—	—	—	—	—	—	—	45 W 2
47 W 1	47 W 5	47 W 2	—	47 W 4	—	47 W 2	47 W 1	*47 W 15*
—	—	49 W 1	—	—	—	—	—	49 W 1
—	—	—	—	—	—	—	50 W 2	50 W 2
52 W 3	52 W 1	—	—	—	—	52 W 2	52 W 2	*52 W 8*
—	57 W 1	57 W 2	57 W 2	—	—	—	57 W 2	*57 W 7*
—	—	—	—	—	—	—	60 W 1	60 W 1
62 W 1	62 W 5	62 W 3	—	—	—	62 W 2	—	*62 W 11*
—	—	—	—	—	—	—	64 W 1	64 W 1
67 W 1	67 W 1	67 W 1	67 W 2	67 W 4	67 W 1	67 W 1	—	*67 W 11*
—	69 W 1	—	—	—	—	—	—	69 W 1
72 W 2	72 W 3	—	—	—	—	—	—	72 W 5
77 W 2	77 W 4	—	—	77 W 4	—	—	—	*77 W 10*
—	—	—	—	—	79 W 1	—	—	79 W 1
82 W 2	82 W 1	—	—	—	82 W 2	—	—	82 W 5
—	85 W 1	—	—	—	—	—	—	85 W 1
87 W 11	87 W 1[1]	87 W 6	87 W 5	—	87 W 3	—	87 W 4	**87 W 40**
42	41	28	25	27	10	9	40	222

The volcanotectonic lines of the Italian peninsula and the neighboring Islands.

Law governing the location of volcanic vents. The alignment of volcanic vents is one of the earliest of geological observations, and their explanation as built up of material brought in a fluid condition through earth fissures has been general. It was in the region here under consideration that manifestations of volcanic energy were first studied, so that the type of composite cone with Somma and Atrium (the *Erhebungskrater* of *v. Buch*) is Vesuvius; Astroni and Monte Nuovo stand for different types of cinder cone, while Stromboli, Etna, Vulcano, the Solfatara, and Monte Albano, are each typical of a special condition of volcanic activity or non-activity.

The greatest extravasations of volcanic material, as *v. Richthofen* showed in 1868, have been not from localized vents, but apparently throughout the entire length of extended fissures. The welling up of such vast quantities of material having taken place largely in Tertiary time, the subsequent denudation has seldom been sufficient to bring to light the fissures themselves. Especial interest therefore attaches to the lava fields of the northwestern British Isles and Iceland, which, as Geikie has shown[1]), may be traced to eruptions through the fissures now represented by the extended basalt dikes of the region. Within an area of probably more than 100.000 square miles, the dikes pierce formations of every age, including the Chalk, traverse even the largest faults, and cross from one group of rocks into another without interruption or deflection. Where interrupted, the dike is resumed after an interval on the continuation of the original direction:

"These fissures, whether due to sudden shocks or slow disruption; were produced with such irresistable force as to preserve their linear character and parallelism through rocks of the most diverse nature, and even across old dislocations having a throw of many thousand feet".

If the lips of fissures which have yielded the great lava field have been separated throughout their length, it is natural to conclude that those upon which local volcanic cones have been built up, are, parted sufficiently to permit the ejection of volcanic materials only

1) *A. Geikie,* The lava fields of northwestern Europe. Nature, vol. 23, 1880, pp. 3—5.

at the vents themselves. The most obvious cause of such local widening is the intersection of fissures having different directions. This quite generally accepted view has been given expression, among others, by *Suess*[1]; and has been given forceful illustration by the arrangement of the Mexican[2] and Central American[3] volcanoes.

The volcanoes near the border of the great Mexican plateau run in parallel series on meridional fissures and the greatest cones are located at the intersection with an equatorial one:

"It is easy to see that the scene of the most intense volcanic activity is, as a rule, to be sought where different systems of fissures cross; in our case, where the meridional secondary fissures meet the main equatorial fissure. Such points are Popocatapetl and Ajusco near Mexico, further, the Nevado di Toluca, mighty strato-volcanoes whose craters served for paroxysmal eruption up to geologically recent times".

The arrangement of Central American volcanoes *en echelon* speaks for a similar arrangement of fissures.

The Italian volcanic vents and their distribution. Without extending our study north of the Roman Campagna, where are chiefly to be found the half-dissected cones of the Euganaen, or to the volcanoes of southern Sardinia; we have to do with a well distributed series of generally isolated vents. Upon the peninsula itself are Vesuvius, the Lazial hills (Monte Albano) near Rome, the great crater lakes of the Campagna — Bolsena, Bracciano, and Vico — Monte Amiata, Monte Vendere and Monte Tolfa, Rocca Monfina, Frosinone, Monte Voltura near Melfi, and the *Campi Flegrei* near Naples.

In the sea off the Phlaegrean Fields are Procida, Ischia and the Ponza islands — Ventotene, La Botte, Ponza, and Palmarola — while in the Tyrrhenian depression farther to the south are the Eolian islands — Stromboli, the group of remnants of which Panaria is the largest, Lipari, Vulcano, Salina, Filicuri, and Alicuri. In an isolated position far to the west of these is Ustica. Upon the island of Sicily is the giant Etna rising nearly 11·000 feet directly from the sea and nearly 100 miles in circumference, the extended tuff masses

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1) Antlitz der Erde. Bd. 1, p. 191.

2) *J. Felix* und *H. Lenk,* Über die tektonischen Verhältnisse der Republik Mexiko. Zeitschr. d. deutsch. geol. Gesellsch., Bd. 44, 1892, pp 303—326, pls. 19—20.

3) *F. de Montessus de Ballore,* Tremblements de terre et éruptions volcaniques au Centre-Amérique depuis la conquête espagnole jusqu'à nos jours, Dijon 1888.

between Mineo and Militello, and Monte Pachino. Out of the submerged plateau joining Sicily to Africa rise Pantelleria and Linosa.

Conical elevations upon the sea floor and submarine volcanic eruptions. Earlier papers upon the arrangement of the volcanic island of the Mediterranean, have not taken into account the recorded submarine volcanic eruptions (which have apparently been as numerous as in any other region of the globe), nor of the very remarkable pinnacle-like elevations upon the surface of the Mediterranean floor. The data concerning the former have never been collected, and *Rudolph's* data [1]) are here particularly meagre. Moreover, the studies upon the Eolian islands have generally started out from the assumption that the Panaria group of fragments constitutes a center from which radial fissures diverge [2]). *Cortese* [3]) alone has indicated the alignments independent of this hypothesis, though he has connected Alicuri and Filicuri with Salina, which is not upon the same line.

Noteworthy local elevations upon the Mediterranean sea floor within the area here under consideration, have been indicated in Figs. 1 and 2. The most striking of all is that which rises in a sharply conical form from depths of 660 meters to 250 meters at a point a few miles northeast of Salina and just where the line joining the crater of Etna to Vulcano and Lipari intersects the line joining Alicuri and Filicuri to Panaria. Another very similar elevation of the sea floor causes a local shoaling of the water from a depth of 710 meters to 74 meters off the Cape Vaticano promontory. On a line connecting it with the crater of Vulcano a similar, though less pronounced, elevation is found. It can hardly be other than significant that the Lipari-Milazzo telegraphic cable has been repeatedly interrupted where it crosses this line [4]). These interruptions have occurred Nov. 21 and 22, 1888; March 30, 1889; Sep. 11, 1889; and Feb. 9, 1893. All these interruptions occurred at or near the same point, which is between two and three miles distant from Vul-

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[1]) *E. Rudolph,* Über submarine Erdbeben und Eruptionen. Beitr. zur Geophysik, Bd. 1, 1887, pp. 133—355, pls. 4—7; Bd. 2, 1895, pp. 537—666.

[2]) *F. Hoffmann,* Über die geognostische Beschaffenheit der liparischen Inseln. Ann. Phys. Chem., 1832, pp. 81—88, pl. 4. — *J. W. Judd,* Contributions to the study of volcanoes. Geol. Mag. — *Ed. Suess,* Über den Bau der italienischen Halbinsel. Sitzungsber. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., Bd. 65, 1872, I. Abt., pp. 1—5. Also, Antlitz der Erde, Bd. 1, pp. 110—114.

[3]) *E. Cortese,* Sulla costituzione geologica dell' isola di Lipari. Boll. Com. Geol. d' Italia. Ann. 12, 1881, pp. 501—523.

[4]) See footnote on page 320.

cano in a direction northeast from the Solfatara and in depths of 400—650 fathoms[1]). The first interruption was almost contempora-

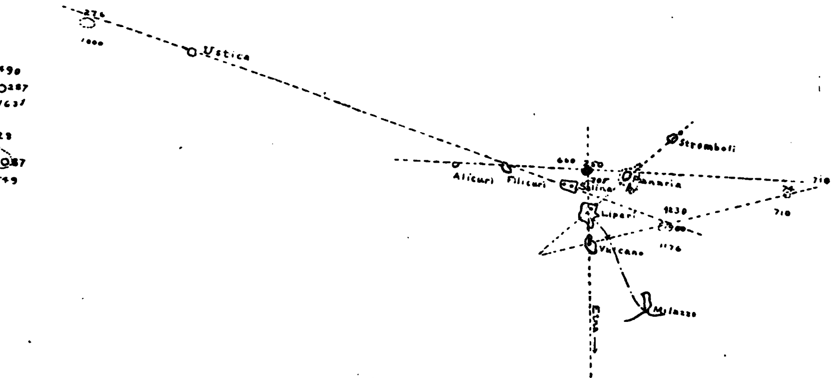

Fig. 1.

Map to show the location of submarine elevations to the northward of Sicily. The figures give the depths of water in meters over and near to the elevations. The alignments are indicated by dotted lines. The course of the telegraphic cable from Lipari to Milazzo is also indicated, as is the place where it has been repeatedly ruptured (from *Andree's* Handatlas).

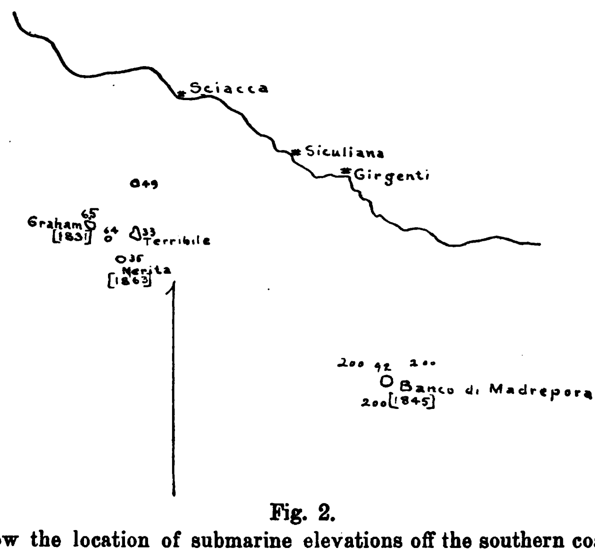

Fig. 2.

Map to show the location of submarine elevations off the southern coast of Sicily. The figures not enclosed in brackets are the depths of water in meters over the shoals and their near-lying platforms, while the bracketed figures give the years when they have been observed in eruption (from *Andree's* Handatlas).

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1) *W. H. Hobbs,* Notes on a trip to the Lipari Islands. Trans. Wis. Acad. Sci., vol. 9, 1893, p. 664. — *J. Milne,* Sub-oceanic changes. Geog. Jour. Lond., vol. 10, 1897, p. 271.

neous with the awakening of Vulcano from a slumber of nearly a century, and as the cable was found buried beneath a mass of materials it has been supposed that its rupture was due to a submarine eruption in its vicinity. The latest break in the cable occurred Sept. 8, 1905 at the time of the great Calabrian earthquake; and as the earlier interruptions all correspond in time either to neighboring earthquakes or to volcanic irregularities in the vicinity, the hypothesis that the point where broken is upon a fissure line and also near a submarine vent is well supported.

To the west and southwest of Ustica are other similar elevations, which from their peculiar forms are doubtless all volcanic in their origin.

In the sea to the south of Sicily and between Sciacca and Pantelleria a group of such conical elevations is to be found. According to Baratta it is believed that the materials of all of them are volcanic[1]). Two, and perhaps three, of these have been in eruption during the last century. The best known is the remnant of Ferdinandea (Isola Giulia or Graham's Island) which rose above the sea in 1831[2]) and disappeared during the same year to rise again in 1833. There is now a depth of 65 meters over the site. The vent seemed in the later stages of the eruption to have moved west, and was several hundred feet west of the shores of the island. In 1835 another eruption occurred in the same vicinity[3]), but its exact location we have not been able to ascertain. On August 12, 1863 a submarine eruption occurred in the same vicinity "where there had been a volcano in 1701 as shown by an old map"[4]). An island here rose above the sea but disappeared through the action of the waves after some days. Owing to the dangers to navigation its exact site was accurately determined by the British Government to be Lat. 37° 9′ 42″ N. and Long. 12° 43′ 52″ E (Graham Island, Lat. 37° 1′ 30″ N and Long. 12° 42′ 15″); which clearly shows that its location was exactly where the Nerita bank now is, and over which there is now a depth of 35 meters.

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1) *M. Baratta,* Sulle aree sismiche italiane. Voghera, 1901, p. 19.

2) *Lyell,* Principles of geology, vol. 2, pp. 58—63. — *Cruon,* Réapparition de l'île Ferdinandea (or Julia) dans la mediterranée, Bull. Soc. géol. France. 2me Sér., vol. 1, 1834, p. 62.

3) *Baratta,* l. c.

4) *A. Perrey,* Note sur les tremblements de terre en 1863, Dijon, 1865, pp. 176—180.

In October of the same year another ephemeral island was discovered in Lat. 37° 50′ N. and Long. 8° 30′ E., about 40 miles northeast of the Cani Rocks, and, as shown by latitude and longitude determination, about 100 kilometers a little to the west of south from Cape Teulada, Sardinia. This island was about 120 meters long as reported by Capt. Aonu of the Tunisian brig, *Wansour*, Perrey considered its formation probably contemporaneous with the Tunis earthquake of the previous month [1]).

A submarine eruption which occurred June 18, 1845, was from the observations made probably over the *Banco di Madrepora* [2]), a pinnacle-like elevation 65 kilometers S. 15° E. from Girgenti, Sicily. Over this bank, there is now a depth of 92 meters.

On October 4 and 5, 1846, a submarine volcanic eruption occurred off Siculiana on the south coast of Sicily. The location is not given more exactly, but was probably near shore; as otherwise one of the larger places, Sciacca or Girgenti, would have been mentioned for location. They are, however, mentioned in the report to locate Siculiana [3]).

October 17—26, 1891 occurred the latest submarine eruption in the area under consideration, the location of the vent being Lat. 36° 50′ 45″ N. and Long. 9° 33′ 15″ E., or 5 kilometers west northwest of the northwest angle of Pantelleria [4]) (not as stated by *Neumayr* [5]) in the direction of Ferdinandea).

Volcanotectonic lines. Attempts to discover the fissure lines upon which volcanic vents are aligned, have seldom taken into account the curvature of great circles of the earth when projected

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1) *A. Perrey,* l. c., p. 189.

2) On June 18, 1845, at 9.30 P. M., the English ship *Victory,* Capt. *Caithness,* while en route to Malta, and in about Lat. 36° 40′ 56″ N. and Long. 13° 44′ 36″ E. (midday observation), had both masts suddenly thrown to one side. Almost immediately the crew found it exceedingly difficult to breath because of the sulphurous emanations and the intense heat. The ship labored heavily and at a distance of half a sea mile three immense columns of flame were seen to rise from the sea and remain visible for about ten minutes. A second heavy wind blast suddenly brought the ship out of the heat into a cold current (Nautical Magazine, vol. 14, 1845, p. 435. Quoted by *Perrey* and *Rudolph*).

3) *A. Perrey,* Liste des tremblements de terre ressentis pendant les années 1845 et 1846, p. 461.

4) *A. Riccò,* Tremblement de terre, soulèvement, et éruption sousmarine à Pantelleria. C. R. de l'Acad. Franc., vol. 113, 1891, pp. 753—755.

5) *Neumayr,* Erdgeschichte, Bd. 1, pp. 187—188.

upon modern maps. It may have been thought that such a correction is an over-refinement of method, since the volcanoes of a train are seldom arranged upon a single line. The possible presence of a fissure system or network which can be determined, has not, however, been generally taken into account, or locations would have been made with greater exactness and with all necessary corrections. Upon the smaller map of plate 2 the attempt has been made to indicate the great circles which connect three or more volcanic vents, or probable vents, within the region here under consideration. The map also shows by the areas which have been outlined in blue, the curiously isolated seismic localities of Sicily, as these have been determined by Baratta[1]). All the Eolian islands and the mass of Etna have been likewise shown to be areas of high seismicity.

It will not be necessary here to enumerate each of these volcanotectonic lines, but their orientation will be fully set forth in tabular form below[2]). The striking alignments within the Eolian group have already been referred to, and attention has been called to the extended line of submarine vents which stretch westward from the Madrepore Bank. The importance of Ustica in the system is seen to be great—it is a cone which in its isolated position rises more than 8000 feet from the profound depths of its basement. Its close seismic relation to Palermo has long been recognised, and Ba-

1) *Mario Baratta,* Carta sismica d' Italia (Aree di scuotimento). 4 colored sheets on scale of 1 to 1500000, with explanatory pamphlet. Voghera, 1901.

2) "The seventh of the Eolean islands is Euonymus (Panaria) farthest in the sea and uninhabited. Its name it owes to the fact that it lies to the left of ships going from Lipari to Strongyle (Stromboli). Flames have often been seen rising from the surface of the sea which surrounds these islands, since it opened a way from the caverns of the depths and the fire burst out with great force. Posidonius relates that in his time at sunrise during the summer solstice the sea rose to an enormous height between Hiera (Vulcano) and Euonymus (Panaria) and for a long time remained in a boiling wall, but was afterward seen to come to rest. Those who dared sail over saw dead fishes drifted by the waves and escaped overpowered by heat and foul odors; one of the boats, however, which approached nearest lost a part of its crew; the others, however, escaped with dificulty to Lipari and in great danger owing to the fact that they became unconscious like swooning persons but returned to their natural consciousness again. Many days later ash was seen upon the surface of the sea in many places, and flames, smoke and steam broke forth." (*Strabo,* Description of the Earth. Book VI, pp. 276—277.)

The above realistic description of a submarine Eruption is most important, and being definitely located between Vulcano and Panaria at a point where escape was made to Lipari, it helps explain the interruption of the Lipari-Milazzo cable

ratta has represented this by a zone which connects the two points oversea; as he has done similarly to connect Pantelleria with Sciacca [1]). This latter zone is continued half across Sicily as has been shown by *Cortese* [2]) in a line of fumeroles and hot springs. That Sciacca and Girgenti should be isolated seismic centers, is here accounted for by their being each located at the intersection of volcanotectonic lines. Siculiana, which is a somewhat less clearly defined center, is at the intersection of the long train of mud volcanoes with a volcanotectonic line. The line joining Etna to Ustica is continued northwestward to the Sardinian volcanoes lying to the northwest of the Gulf of Orosei and to the great vent of Monte Sassu near the Gulf of Asinara.

Seismotectonic Lines of Calabria and northeastern Sicily.

Construction of maps.

The methods employed in the investigation described in the following pages were evolved as the result of observations made in Calabria after the earthquake of 1905. This devastating earthquake, the greatest in the province since 1783, began without warning between 2.30 and 3 o'clock on the morning of September 8 and lasted about 40 seconds. It cost upwards of 800 lives, wounded several thousand persons, and caused nearly complete destruction of numerous villages scattered almost throughout Calabria. The writer left Naples for Calabria October 14 and spent nine days in visiting a selected number of communes which were distributed between Rossano upon the north and Reggio upon the south. It is proposed here to treat of the earthquake in its geographic and directional aspects only; since two separate Royal Commissions, each consisting of a number of prominent Italian seismologists, have been at work with better facilities for collecting data and for arriving at the results usually sought in seismological investigations.

The first suggestion of the localization of the shocks upon comparatively narrow lines was obtained in Monteleone; where one could look down a considerable distance of the *Strada Forgiara* and see walls levelled on both sides, though elsewhere in the city they had

1) *Baratta,* Carta sismica d' Italia.

2) *Cortese,* Descrizione geologica della Calabria, p. 36.

not been overturned. Of equal interest is it, through this was not learned until later, that this street had been levelled by the first shocks of the great earthquake of 1783 [1]).

The headquarters of General Ferrario, who was in command of the troops engaged in succoring the wounded and homeless after the disaster, had been located at Monteleone; and through the kind offices of Sig. Avv. Oreste Daffinà representing the *Agenzia Stefani* and of Professor *Giulio Cesare Bernardi*, Preside del Ro. Liceo di Monteleone, the opportunity was afforded of meeting General Ferrario and his Chief of Staff, Colonel Riccardi. Upon a large military map (scale 1 : 100·000) staff officers had carefully plotted from reports submitted from subordinate commands the relative needs in each commune and fraction thereof throughout the entire province. This map was thus in reality a map showing the distribution of the damage which had resulted from the earthquake; and those villages which had been almost completely destroyed were indicated upon the map by a special colour. A mere glance revealed the fact that the earthquake had exercised, if one may so express it, a selective property — the damaged communes, and the ones destroyed especially, were arranged on essentially right lines. This fact had not failed to impress Colonel Riccardi, who had further noticed that the lines in a general way ran parallel to the bases of mountain masses.

The importance of this discovery to a proper understanding of the nature of earthquakes was at once appreciated; and so soon as the field study had been completed, an extensive investigation of the distribution of damage by earlier earthquakes within the province was undertaken at Rome, where with the aid of accurate large scale maps (1 : 50·000) and with detailed gazetteers [2]) accurate maps were prepared to show the distribution of damaged villages for all the important earthquakes of the province during the last three centuries. The area thus examined includes besides Calabria that portion of Sicily which lies to the north of Etna and to the east of Naso, as well as the Eolian or Lipari Islands; since these separate land areas seem to belong together in what may perhaps with some propriety be termed a seismotectonic province.

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1) *Mario Baratta,* Il grande terremoto Calabro dell' 8 Settembre 1905, Osservazioni fatte nei dintorni di Monteleone. Pisa, 1906, p. 13.

2) Nuovo dizionario dei comuni e frazioni di comuni del Regno d' Italia. Enrico Voghera, Rome, 6th. ed., 1902. — Dizionario dei Comuni del Regno e delle frazioni etc., Botta, Rome, 1895.

In Calabria records of earthquakes have been carefully preserved, and the world is indebted in no small measure to Dr. *Mario Baratta*, who in the most comprehensive work yet carried to completion for any single earthquake region, has carefully collected and edited these reports[1]. The writer's indebtedness to Dr. *Baratta* is very great, not only because this valuable work has supplied much of the material for investigation, but also for data supplied in correspondence. Another very extensive and valuable work upon the Calabrian earthquakes is the somewhat earlier one of Mercalli[2]. The monograph by *Suess*[3] printed in 1872 is of great importance, since at that early date the localization of earthquake shocks upon certain definite lines was pointed out.

For the better presentation of the results of this study, the five devastating earthquakes of 1638, 1659, 1783, (1894), and 1905 have been entered upon a single large map (plate V, Fig. 2). The distribution of damage from the less heavy quakings have been set forth upon smaller maps, which fall mainly into two groups: 1. those earthquakes which have affected northeastern Sicily, the Eolian islands, and the neighboring portions of southern Calabria; and 2. those which have been largely restricted in their distribution to northern Calabria, or to the vicinity of the Sila and Cocuzzo masses.

The larger map in particular allows of a comparison of the seismic with the geologic data; as it does also in a very striking manner of the three great seisms with each other. No less noteworthy comparisons, and perhaps even more valuable ones, are possible from a study of the smaller maps; for the reason that the selective quality of earthquakes becomes the more apparent as the difficulties of grading the intensity are removed.

On the map of plate V, Fig. 2 an attempt has been made to outline the destructive areas of the great Calabrian earthquakes, though this can be done only in a most general way, since it is found that apparently isolated places often far removed from the general area affected by an earthquake are sometimes subjected to shocks of considerable violence.

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1) *Mario Baratta,* I terremoti d' Italia, Saggio di storia geografia e bibliografia sismica italiana. Con 136 sismocartogrammi. Turin, 1901, pp. 950.

2) *Giuseppe Mercalli,* I terremoti della Calabria Meridionale e del Messinese, Saggio di una monografia sismica regionale. Mem. della Società Italiana delle Scienze, ser. 3, vol. 11, pp. 117—266, pls. 2.

3) *Ed. Suess,* Die Erdbeben des südlichen Italiens. Denkschr. d. k. Akad d. Wiss. zu Wien, Math.-naturw. Kl., Bd. 34, 1872, pp. 1—32, pls. 3.

Comparison of the intensity map of the earthquake of 1905 with those of the great earthquakes of 1659 and 1783.

The destructive area of the earthquake of 1659 is wholly included within those of 1783 and 1905, and part included in the area of 1638. The opportunity is thus offered to compare the distribution of intensity in three devastating earthquakes on common territory. Since the epicenters for these earthquakes have been located at widely separated points (see plate V, Fig. 2) there is the further opportunity to subject the centrum theory of earthquakes to a particularly discriminating test. Should that theory be supported, the communes involved should indicate relative intensities of shock notably different in the three cases and dependent in each instance upon the distances from the epicenters.

In the following table there have been brought together in parallel columns and with alphabetical arrangement the communes and their fractions which have suffered damage from the several earthquakes in question. The data for the years 1638, 1659, and 1783 have been extracted from *Baratta's* great work already mentioned, those for 1783 being supplemented for northern Calabrian communes from the great report of the Naples Academy of Science[1]).

The figures for 1905 have not heretofore been published and have been furnished by the Italian Government only after earnest and persistent solicitation by the American Embassy at Rome. To Ambassador *White*, and to Mr. *R. S. Reynolds Hitt*, First Secretary of the Legation, the author has been placed under obligation.

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1) Istoria di fenomeni del tremoto avvenuto nelle Calabrie e nel Valdemone nell anno 1783, posta in Lucca dalla Reale Accademia delle Scienze e delle Belle Lettere di Napoli, pp. XIV and 351. Folio. With atlas of 69 plates. Naples, 1784.

Comparative table showing losses in life and property within the destructive area common to the Calabrian earthquakes of 1659, 1783 and 1905, and including a part of the destructive area of the earthquake of 1638.

An asterisk after the name of Commune indicates that it lies on the border of the destructive area of the earthquake under which it is entered.

A dagger after the name of a Commune indicates that it has never been rebuilt since its destruction.

Earthquake of 1638	No. of persons killed	No. of houses ruined	Earthquake of 1659	No. of persons killed	No. of houses ruined	Earthquake of 1783	No. of persons killed	Est. damage in thousands of ducats	Earthquake of 1905	No. of persons killed	No. of persons seriously wounded	Est. damage in thousands of lire	Population in 1902
—	—	—	—	—	—	*Acquaro di Arena*	10	150	*Acquaro di Arena* (Including Limpidi)	—	11	200	2711
—	—	—	Amaroni	—	lesioni	Amaroni	4	60	Amaroni	—	—	50	1342
—	—	—	*Arena**	—	114	*Arena*	33	180	Arena	—	—	15	2892
—	—	—	—	—	—	Argusto	—	30	Argusto	—	—	10	812
—	—	—	*Badolato*	19	140	Badolato	2	60	Badolato	—	—	91	4556
Belforte	13	25	Belforte (Bello-forte	6	16	—	—	—	—	—	—	—	337
—	—	—	Bivongi	—	24	Bivongi	—	40	Bivongi	—	—	116	3118
—	—	—	Borgia*	—	24	**Borgia**	332	300	**Borgia**	2	12	228	4323
—	—	—	Brazzario (incl. Seminatri)	—	31	—	—	—	—	—	—	—	—
*Briatico**	—	74	**Briatico***	56	89	**Briatico**	60	150	**Briatico**	32	14	351,5	3639
—	—	—	Brognaturo (Brugnaturo)	—	26	Brognaturo	—	30	Brognaturo	—	—	2	810
—	—	—	*Calabro**	1	15	Calabro†	26	70	—	—	—	—	—
—	—	—	Camini	—	14	Camini	—	30	Camini	—	—	12	1169
—	—	—	Capistrano	16	46	Capistrano	2	40	Capistrano	—	—	20	1351
—	—	—	Cardinale	—	47	Cardinale	1	50	Cardinale	—	—	25	3753
Castelmonardo	63	nearly all	Castelmonardo	193	nearly all	Castelmonar-do†	60	200	**(Filadelfia)** (On site of Castel-monardo)	3	34	120	6634

Earthquake of 1638	No. of persons killed	No. of houses ruined	Earthquake of 1659	No. of persons killed	No. of houses ruined	Earthquake of 1783	No. of persons killed	Est. damage in thousands of ducats	Earthquake of 1905	No. of persons killed	No. of persons seriously wounded	Est. damage in thousands of lire	Population in 1902
—	—	—	*Caulonia** (Castelvetere)	14	67	**Caulonia Castelvetere**	95	250	Caulonia	—	—	20	9152
—	—	—	Cenadi? (Lucenadi)	—	13	Cenadi	2	30	Cenadi	—	—	—	1052
—	—	—	Centrache	—	38	Centrache	—	25	Centrache	—	—	—	1404
—	—	—	—	—	—	Ciano	6	70	—	—	—	—	—
Chiaravalle	—	„91 damaged"	**Chiaravalle**	67	all	Chiaravalle	2	70	Chiaravalle	—	—	11	4765
—	—	—	Comparni (incl. S. Pietro, Paravati, Nao and Jonadi)	—	50	**Comparni**†	24	100	—	—	—	—	—
—	—	—	*Dasa**(incl. Prunia and Migliano)	17	59	**Dasa**	55	150	***Dasa***	—	38	15	1854
—	—	—	Davoli	15	62	Davoli	8	70	Davoli	—	—	100	3137
—	—	—	Dinami* (incl. Melicucca)	—	34	*Dinami*	35	80	*Dinami* (incl. Melicucca)	2	13	30	2500
Filogaso	100	118	**Filogaso**	161	nearly all	*Filogaso*	6	50	Filogaso	—	—	—	786
—	—	—	—	—	—	Fabricia	1	30	Fabricia	—	—	—	5769
*Francavilla**	20	71	Francavilla Angitola*	5	32	**Francavilla**	43	150	**Francavilla**	—	17	158	2159
Francica*	1	11	*Francica*	19	71	*Francica*	25	70	*Francica*	1	15	42	1539
—	—	—	—	—	—	—	—	—	Filadelfia (On site of Castelmonardo)	3	34	120	6634
—	—	—	—	—	—	Gagliato	—	25	Gagliato	—	—	5	910
—	—	—	—	—	—	Gasperina	9	70	Gasperina	—	—	20	3935

—	—	—	Gerogarne	71	137	*Gerocarne*	22	80	Gerocarne	—	8	23	2062
Girifalco	54	nearly all	*Girifalco**	2	96	Girifalco	184	150	*Girifalco*	—	—	262	5250
—	—	—	*Guardavalle*	—	110	Guardavalle	2	40	Guardavalle	—	—	75	4106
—	—	—	Jonadi (incl. under Comparni)	—	—	Jonadi	1	225	Jonadi	—	17	59	1232
—	—	—	Isca	14	67	Isca	—	30	Isca	—	—	145	2674
—	—	—	—	—	—	*Limpidi*	15	40	Limpidi (Included under Acquaro)	—	—	—	635
—	—	—	—	—	—	Longobardi	—	20	Longobardi	—	—	—	677
—	—	—	Melicuccà* (incl. under Dinami)	—	—	*Melicuccà*	10	80	Milicuccà (Incl. under Dinami)	—	—	—	408
—	—	—	Migliano (incl. under Dasa)	—	—	Miglianò †	3	40	—	—	—	—	—
—	—	—	—	—	—	Mileto	50	200	Mileto	2	49	280	2615
—	—	—	Monasterace	66	17	Monasterace	1	40	Monasterace	—	—	—	1283
—	—	—	Montauro	—	15	Montauro	—	30	Montauro	—	—	80	1867
—	—	—	Monteleone*	—	lesioni castlo damaged	Monteleone	14	150	Monteleone (Including Tripani)	49	95	{440 830	13481
—	—	—	Montepaone	—	60	Montepaone	2	30	Montepaone	—	—	50	1645
Monterosso	—	35	*Monterosso*	16	45	*Monterosso*	18	80	Monterosso	2	—	400	2617
Montesanto	20	nearly all	Montesanto (Roccangitola)	8	18	Montesanto †	—	15	—	—	—	—	—
—	—	—	Montesoro	—	13	Montesoro	3	40	—	—	—	—	—
—	—	—	Nao (incl. under Comparin)	—	—	Nao	1	20	—	—	—	—	350
—	—	—	—	—	—	—	—	—	Nardo di Pace	—	—	—	667
—	—	—	Nicastrello	1	10	Nicastrello	—	20	—	—	—	—	75
—	—	—	Olivadi	66	85	Olivadi	—	20	Olivadi	6	33	200	1234
—	—	—	Palermiti	—	many lesioni	Palermiti	4	30	Palermiti	—	—	100	2009
Panaia (Spilinga)	80	all	Panaia (Spilinga)	496	nearly all	Panaia di Tropea	2	30	—	—	—	—	98
—	—	—	Paravati (incl. under Comparni)	—	—	Paravati	1	40	—	—	—	—	788

Earthquake of 1638	No. of persons killed	No. of houses ruined	Earthquake of 1659	No. of persons killed	No. of houses ruined	Earthquake of 1783	No. of persons killed	Est. damage in thousands of ducats	Earthquake of 1905	No. of persons killed	No. of persons seriously wounded	Est. damage in thousands of lire	Population in 1902
—	—	—	Pazzano	—	14	Pazzano	—	20	Pazzano	—	—	—	1725
—	—	—	Petrizzi	1	8	Petrizzi	3	40	Petrizzi	—	—	5	2163
Piscopio	—	57	**Piscopio***	3	135	**Piscopio**	14	60	**Piscopio**	59	50	200	1303
—	—	—	*Pizzone*	1	50	*Pizzone*	21	80	Pizzone	—	—	14	2090
—	—	—	Placanica	1	25	Placanica	—	20	Placanica	—	—	21	1846
Polia	—	124	**Polia**	203	nearly all	**Polia**	26	150	**Polia**	2	—	290	3029
—	—	—	Prunia (incl. under Daza)	—	—	**Pronia** †	7	50	—	—	—	—	—
—	—	—	Riaci	—	62	Riaci	1	20	Riaci	—	—	10	2109
—	—	—	**S. Angelo**	13	15	**S. Angelo** †	5	30	—	—	—	—	—
—	—	—	*S. Caterina del Jonio*	26	111	S. Caterina del Jonio	—	30	S. Caterina del Jonio	—	1	35	3200
—	—	—	—	—	—	S. Constantino di Francica	9	60	S. Constantino Calabro	—	—	95	2403
—	—	—	**S. Dimitri** †	16	all	—	—		—	—	—	—	—
—	—	—	S. Elia	—	21	S. Elia †	12	50	—	—	—	—	—
—	—	—	**S. Floro**	1	55	**S. Floro**	106	150	**S. Floro**	1	12	260	1377
S. Gregorio	—	7	**S. Gregorio**	6	252	**S. Gregorio**	8	60	**S. Gregorio** (Incl. Zammarò)	73	70	447,9	1654
—	—	—	*S. Nicola (da Crisa)*	39	93	*S. Nicola di Vallelonga*	7	60	S. Nicola da Crissa	—	—	70	2812
—	—	—	*S. Onofrio*	9	36	*S. Onofrio*	7	60	S. Onofrio	14	317	300	3617
—	—	—	S. Pietro (incl. under Comparni)	—	—	S. Pietro di Mileto †	1	30	—	—	—	—	—
—	—	—	S. Sostene	4	36	S. Sosté (?)	—	20	S. Sostene	—	—	—	2292
S. Vito*	—	7	*S. Vito al Jonico*	16	56	S. Vito	1	30	*S. Vito*	—	3	105	3242
—	—	—	*Satriano*	11	96	Satriano	2	30	Satriano	—	—	81	2826

—	—	—	*Serra S. Bruno* (incl. Spadola)	—	106	*Serra S. Bruno*	42	150	Serra S. Bruno	—	—	16,7	6497
—	—	—	—	—	—	Simbario	9	50	Simbario	2	—	20	1885
—	—	—	—	—	—	Soriano	161	250	Soriano Calabro	—	3	25	3172
—	—	—	—	—	—	—	—	—	Sorianello	—	—	—	1226
—	—	—	Soverato	—	25	Soverato	1	15	Soverato	—	—	50	1780
—	—	—	Spadola (incl. under Serra S. Bruno)	—	—	*Spadola*	4	50	Spadola	—	—	34	788
Squillace*	—	36	Squillace	—	30	Squillace	15	80	Squillace	—	—	75	3122
Staletti*	—	17	Staletti	—	many lesioni	*Staletti*	17	70	Staletti	—	—	40	1782
—	—	—	Stefanaconi	64	82	Stefanaconi	25	90	Stefanaconi	68	123	420	1903
—	—	—	*Stignano*	2	68	*Stignano*	15	60	Stignano	—	—	31	2025
—	—	—	Stilo	—	20	Stilo	1	30	*Stilo*	—	—	135	3177
—	—	—	Torrepalota (?)	3	37	Torre	4	30	Torre diRuggiero	—	—	26	785
—	—	—	Triparni	—	49	Triparni	28	100	Triparni (Incl. in Monteleone)	39[1])	—	—	342
—	—	—	—	—	—	—	—	—	Vallefiorita	—	—	65	1256
—	—	—	Vallelonga	53	79	Vallelonga	28	100	Vallelonga	—	—	50	2283
—	—	—	Vazzano	63	74	Vazzano	29	80	Vazzano	—	2	2,3	1475
—	—	—	Zimmarino	19	60	Zammarò	14	40	Zammarò	—	—	—	548

1) Unofficial.

It is not found to be true that the heaviest shocks are concentrated at the geographic centers of the affected areas, though it does appear that intensity is seldom of the first order of magnitude near the margin of a destructive district; and hence in comparing the damage done to the same commune by successive earthquakes, indication has been made by an asterisk if the commune in question lies on or very near to the border of the destructive area from any particular seism.

The intensity of local shocks has been roughly gauged in each instance by two of three factors, the best that appear to be available. These are, 1. the number of persons killed, 2. the number of houses ruined, and, 3. the estimated value of the property destroyed. Of all these the number of houses ruined is by far the most reliable for purposes of comparison, but unfortunately it is not always a matter of record. The same type of house, and here the worst possible for an earthquake district, appears to have been constructed and reconstructed through centuries; though the opportunity seems never to have been lost to point a moral after each succeeding disaster. Throughout the *paese* houses are constructed from the rounded boulders (the ever ready products of the *fiumare*) which are cemented by a weak mortar of home production, and roofed with tiles loosely supported upon poles. It is not too much to say that saving to life from proper house construction throughout Calabria would at thetime of earthquakes reach fully three-fourths.

The losses to life are for comparative purposes generally the least reliable of the three, since they depend chiefly upon whether shocks occurred during the night when the population was asleep under roofs, or in the day when the people were in the field; as they do also upon the relative order of the lighter and the heavier shocks. These figures are, however, the easiest to obtain; and since the great shocks of 1638, 1659, and the heavier of those in the series of 1783 came either during the day or the early evening a valuable comparison is possible even on this basis.

It will be observed that in the table much the same relative intensity has been characteristic of each place during successive macroseisms, with noteworthy exceptions when the communes have been located near the border of any of the destructive areas. No relation whatewer between local intensity of shocks and distance from the epicenter is perceptible. The location of the communes and the relative intensity of shocks at each appear also upon the comparative

figures presented on plate VI. Only less striking comparisons are furnished by other sections of the large map, but the central area will suffice for illustration. It is of considerable interest to note that in at least one instance a city which has been repeatedly destroyed by earthquakes (Castelmonardo) has by a chance relocation (Filadelfia) apparently secured a safer basement. It is believed that the table clearly reveals the falsity of the centrum conception — a theory which grew not from experimental data, but from the once generally held preconception that earthquakes were intimately dependent upon the forces which are called volcanic[1]).

Seismotectonic lines revealed by the earthquakes of 1638, 1659, 1783, 1894, and 1905.

A glance at the map of plate III will show that the communes which are notable by reason of their susceptibility to seismic disturbances, betray an arrangement within definite lines which in many cases at least are revealed as lineaments upon the surface. Such lines are here designated *seismotectonic lines.*

Considering first Sicily, it is noted that the fault line of the eastern coast has ranged upon it the seismically important communes of Riposto, Taormina, S. Teresa, Guidomandri, Messina, and Ganzirri. Parallel to and near the northern coast are found in similar alignment; Naso, Patti, Pozzo di Gatto, Condrò, Rocca Valdina, Calvaruso and Messina. Hardly less notable in the same respect are two interior lines: the one connecting the prominent headlands of the northwest and southeast coasts separating the schist-gneiss mass of northeastern Sicily from the mass of Etna: and the other forming the northwest boundary of both the Peloritani mass and the Etna block. Upon the first mentioned are located Patti, Castiglione di Sicilia, Linguaglossa, Mascali, and Riposto; and upon the other Bronte, Randazzo, Rocella Valdemone, S. Lucia, Condrò, and S. Martino. A fifth line passing through Condrò, Valdina, Venetico, Saponara Villafranca, and Forte Spuria, with the exceptions of Milazzo, Castroreale and Francavilla, exhausts the list of the seismically more important communes of northeastern Sicily.

Upon the mainland of Italy, a seismic area of far greater intensiveness, the problem is far more complex: yet the prominence of certain well determined lines is no less remarkable. One of these

1) See Seismic geology.

continues the faulted coast line between Palmi and Bagnara southward through Solano, S. Alessio, and Cataforio to Motta. Perhaps the most dangerous zone in all Calabria lies on the northern boundary of the Aspromonte, and includes S. Eufemia d'Aspromonte, Sinopoli, Acquaro di Sinopoli, S. Giorgia, Cosoleto, the site of the ruined Lubrichi, Oppido Mamertino, and Tresilico. Westward its continuation reaches Solano, Villa S. Giovanni, Messina, Rometta, and Monforte. On this line the loss of life in 1783 reached astounding proportions. The nearly perpendicular direction which joins Palmi to Delianuova and passes near to or through Seminara, S. Anna di Seminara, Mellicucca, S. Procopio, Sinopoli, Podavoli and Paracorio is, save for its short length, hardly less noteworthy.

Farther to the north in central Calabria greatest interest attaches to the walls which border the broad valley of the Mesima at the margins of the Vaticano and Pecoraro masses. On the west of the valley two strong seismotectonic lines converge at S. Gregorio. One of these can be followed from Reggio through Palmi and Rosarno and Melito to S. Gregorio, Zammarò, Piscopio, Stefanaconi and S. Onofrio; while the other aligns a number of small villages and sites of former villages with S. Costantino Calabro, S. Gregorio, the site of Castelmonardo, Girifalco, and Catanzaro. The southeastern valley margin of the Mesima is formed by a veritable chain of communes seismically of the first importance. This line *Suess* has brought into prominence by his excellent monograph [1]). At the Straits of Catanzaro the faults on the north margin of the Filadelfia mass come into prominence through their seismic movement.

In northern Calabria no single seismotectonic line is perhaps more strikingly marked out than that which straightens the eastern margin of the Sila by including Cropani, Belcastro, Arietta, Mesuraca, Petilia Policastro, Cotronei and Cerenzia. The greatest seismic intensity has, however, characterized the margins of the broad valley of the Crati and lines near to them. One of these latter passes through Pedavigliano, Rogliano, S. Stefano di Rogliano, Mangone, Cellara, Piane Crati, and Pietrafitta. At Pietrafitta a new direction is taken so as to include Pietrafitta, Pedace, Spezzano Piccolo, Spezzano Grande, and Celico [2]). On the western border of the Sila the seismic communes of Bisignano, Luzzi, Rose, Castiglione Costantino, Zumpano

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[1]) *Ed. Suess,* Die Erdbeben des südlichen Italiens. Denkschr. d. k. Akad. d. Wiss. zu Wien, Math.-naturw. Kl., Bd. 34, 1872, pp. 1—32, pls. 3

[2]) See below.

and Torzano are aligned. Much importance has always attached to a line passing west northwest from Gimigliano through Serrastretta to Decollatura, Conflenti, Martirano, Aiello, Terrati and S. Pietro di Amantea.

The names of communes which have been entered upon the map of plate III are given prominence according to their seismic importance only. As has been stated, the map is a seismotectonic one, and the largest of the places indicated are often the least noteworthy seismically [1]).

The heavier earthquake shocks seriously disturb so much of their destructive areas that the difficulties in the way of grading the local intensity tend to obscure the positions of the lines of maximum shocks. Any attempt to indicate them completely through the joining of the damaged communes which are in alignment, brings with it the danger of confusing merely fortuitous coincidence with significant genetical relationship. Many belts are so strikingly marked out as to leave one in little doubt; but of others genetical relationship upon this basis only is at least equivocal. Fortunately the same difficulties do not apply to a study of the lighter shocks, where the failure to sense them at all eliminates the towns of lowest grade of intensity of shock and brings into striking prominence the communes of high seismicity. The lighter earthquakes seem, therefore, to be the most satisfactory guides to a seismologic study of the province. The tectonic significance of certain lines being thus established, it is proper to assume that if they are the locus of serious damage at the time of a macroseism, movement has occurred upon them.

The Calabro-Sicilian maps showing the distribution of intensity in the microseisms (or in the areas less heavily shaken by macroseisms) for the years 1693, 1783, 1818, 1823, 1832, 1835, 1854, 1865, 1870, 1886 (North Calabria), 1886 (Sicily), 1887, 1892, 1893, 1894 and 1898 (see Figs. 10—15 and 1—6 on plates VII—IX); are thus the warrant for the elaboration of detail upon plate III. Even the network displayed upon that plate probably includes none save the leading planes of a system which extends even to the joints observed at individual outcrops.

In the case of lighter earthquake shocks it is the strongly marked lineaments which are revealed seismically. Heavier shocks bring into prominence the same planes, and show less clearly a series of others

[1]) Those communes not named upon the map may be learned by reference to the extended table given below.

which divide up the main blocks outlined by the former. Thus the Sicilian earthquake of 1893 revealed adjustments within the great blocks lying to the northwest of Etna, the boundaries of which had been sketched by the earthquakes of 1693 and 1783 (the territory in question being on the margin of the latter and relatively lightly shaken).

From a study of all the maps, the principal seismotectonic lines have been found to be as given in the following table, where they have been arranged with regard to orientation. The relative seismicity of each commune has been roughly indicated by three grades (Capital, Italic and Roman letters in correspondence with map legend), to which a fourth grade should be mentally added — the communes which because of their practical immunity from seismic disturbance are not mentioned. If the communes represented upon plate 2 include a relatively large proportion of all within the province, the corresponding proportion in the cases of those shown upon the other maps is relatively small. The directions assigned to seismotectonic lines in the table have been taken not from plate 2 but by noting the direction of the communes in alignment upon the original and official maps of the Italian Geological Survey. Small errors enter because of the slight curvature of such lines upon polyconic projections.

As regards the nature of the underlying terrane, by far the arger number of seismically important communes are situated either on or near the common boundary of the harder and the softer basement. This is adequately explained by the fact that these borders are known to be generally the projection of fault planes upon the surface, and are probably so in all cases. The influence of the nature of the basement in determining the intensity of local shocks is not thereby excluded from consideration, though the absence of any apparent relation between local intensity and the position of supposed centrums combined with the alignment of the seismically important communes, is reason for assigning little weight to it. The prominent lines numbered VIII and XXIV upon plate III cross the hard basement, while XXIII runs throughout over the softer material.

Study of the maps has led to the conclusion that the damage sustained at the time of earthquakes is *very largely* localized either over or near to fissure planes within the crust, and is to be ascribed either directly to the shearing movement upon these planes or to elastic waves which are transmitted *mainly along* them. At distances

exceeding a kilometer to either side of fault planes the shocks from all save the grandest disturbances are probably impotent against well constructed buildings. This view will doubtless seem to many a somewhat startling one, but it is nevertheless the direction in which the facts seem to point. The tectonic quakes as they have usually been described give the impression that the movement which caused the shocks was localized generally upon a single plane, the position of which has often been indicated more or less precisely; and the damage has been ascribed to elastic waves sent out in all directions with approximately equal velocity from that plane, and quite often from either a point or a small area upon it. It is inconceivable that such a movement should occur unaccompanied either by warping of the rock beds or by movements on other fracture planes within them. As we have elsewhere attempted to show [1]) the fault planes which have been revealed at the surface of the earth at the time of macroseisms, are without exception faults of the normal type with steep and nearly vertical hade. Such a condition seems to exclude the possibility of any extensive warping of the beds and leads to the assumption that though the largest movements may indeed be localized upon one or at most a few planes, adjustments of smaller amplitude occur upon a relatively large number of planes of the fracture system which is everywhere present.

Principal seismotectonic lines of Calabria, Northeastern Sicily and the Eolian Islands.

Bearings from northeast to southwest.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 1 E	*Reggio Calabro, Catona,* Villa San Giovanni.	37—XLIII,[2]) also Plate XI	1783, 1894.
N 1 E	Precacore, *Natili,* Melicucco, Feroleto, Borello, Comparni, Mileto, S. Constantino Calabro, Vena di Sotto, Triparni, *Porto Salvo.*	14—XXXVI	1783, 1905.
N 1 E	Martirano, Altilia, Malito, *Dipignano,* Cosenza.	Near XXXI	1638, 1783, 1854, 1905.

1) Seismic geology.

2) Rhoman numbers and numbers bearing no indication belong to plate III.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 1 E	**Siderno, Grotteria, Francavilla,** Sambiase, ***Motta,*** Belsito, Donnici, S. Ippolito, **Castiglione Cosentino,** ***Rose,*** Luzzi, **Bisignano,** Stazione Spezzano, Castrovillari.	XXXI, also P. VII, 10	1638, 1783, 1835, 1887, 1905.
N 1 E	Riaci, Camini, S. Sostene, *Davoli,* Satriano, **Caraffa, Marcellinara.** Cicale.	Near XXIV	1638, 1659, 1783, 1905.
N 1 E	Pontegrande, Pentone, Fossato, Marinise, Taverna.	South margin of Sila	1783.
N 1 E	Cropani, Belcastro, Arietta, Mesuraca, Petilia Policastro, Cotronei, Cerenzia.	I	1638, 1783, 1832, 1905.
N 1 E	Sellia, Magisano, Rossano.	P. VIII, 14	1783, 1832, 1905.
N 1 E	Catania, S. Agata, Trecastagne.	P. IX, 4	1693.
N 1 E	S. Domenica, Floresta, S. Pietro, **Patti,** Lipari.	P. IX, 1	1893.
N 1 E	***S. Pietro in Amantea,*** **S. Benedetto, S. Marco,** Altamonte, Lungro.	Near east margin of Cocuzzo	1905.
N 3 E	**Randazzo, Patti,** Vulcano (former crater).	40 also P. IX, 1, V, 1	1783, 1894.
N 5 E	*Paola, S. Caterina, Albanese,* Acquaformosa.	P. VII, 10	1887.
N 6 E	**Polistena, Laureana, Francica, Monteleone, Marano Marchesato.**	P. VII, 11	1783, 1886, 1905.
N 7 E	Stazione Isola-Capo Rizzuto, Cutro, Rocca di Neto, Melissa.	P. VIII, 14; east of Sila	1832, 1905.
N 7 E	*Dipignano,* Cosenza, **Bisignano,** Cassano, S. Lorenzo della Valle, S. Lorenzo Belizzi.	P. VIII, 13	1638, 1835, 1905.
N 7 E	*Squillace,* Longobucco, Rossano.	P. VIII, 12	1870, 1905.
N 8 E	Acireale, S. Maria di Malati, S. Guardia, Mangone, S. Leonardello, Tre Punti, S. Matteo, Mascali, Piedimonte.	P. X	1865.
N 8 E	*Scigliano, Carpenzano,* **Rogliano,** *Piane Crati, Pedace, Spezzano Piccolo, Spezzano Grande, Celico,* S. Cosimo, Stazione Sibari.	P. VIII, 15, VII, 10	1638, 1783, 1854, 1887, 1905.
N 9 E	*Tiriolo,* Longobucco, Rossano.	P. VIII, 13	1783, 1835, 1905.
N 9 E	Mascalucia, Pedara, *Castiglione di Sicilia.*	P. IX, 4	1693.
N 9 E	Bruzzano, Caraffa di Bianco, Casignana, Carere, *Acquaro,* Dasà.	—	1783, 1905.
N 10 E	Tremestieri, Trecastagne, Fleri, **Linguaglossa,** *Castroreale.*	P. X	1693.
N 10 E	Argusto, Palermiti, Vallefiorita, **Caraffa, Marcellinara,** Longobucco, Rossano.	Near center of Sila	1638, 1783, 1905.
N 11 E	**Linguaglossa,** *Castroreale,* **Milazzo,**	P. IX, 5	1783.
N 12 E	Roccella Valdemone, S. Barbara, Oliveri, Stromboli.	P. IX, 1	1893.
N 15 E	**S. Stefano di Rogliano,** *Figline Vegliaturo, Aprigliano, Pietrafitta,* Rosita.	P. VIII, 15	1638, 1783, 1870, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 15 E	**Gerace**, **Agnana**, **Mammola**, **Serra S. Bruno**, **Spadola**, Simbario, **Cortale.**	P. VII, 11, P. III	1783, 1894, 1905.
N 16 E	*Giarre,* Fiumefreddo, Calatabiano, *Sampiere,* Valdina, *S. Martino.*	P. IX, 6	1783, 1818.
N 16 E	Bongiardo, S. Venerina, Dagala, Fondo di Macchia, S. Giovanni.	P. X	1865.
N 16 E	Etna, Majo. Malvagne, Tripi, Fornari.	P. IX, 1	1893.
N 16 E	Motta S. Giovanni, Armo, *Cataforio,* **Mosorrofa**, Paviglianа, Straorina, Arasi, *Schindilifera,* **S. Alessio**, Solano, **Bagnara.**	16–XLV	1783, 1894, 1905.
N 17 E	Longobardo, **Montalto Uffugo**, Stazione Spezzano Castrovillari, Cassano.	P. VII, 10	1887.
N 18 E	**S. Eufemia d'Aspromonte**, **Mellicucca**, **S. Anna di Seminara**, Moladi, *Rombioia,* Pernocari, Papaligioni, *Cessaniti,* Favelloni, Pannecone. Paradisone, Falerno, S. Maugo, *Grimaldi,* Donnici, S. Ippolito, *Lappano.*	13	1783, 1894, 1905.
N 19 E	*Taormina, Rometta,* Calvaruso.	P. IX, 1, 5	1894.
N 21 E	S. Mauro, Marchesato, Melissa, Ciro.	P. VIII, 14	1832.
N 21 E	**Cittanova**, Limpidi, **Filadelfia**, *Curinga,* Pianopoli, **Feroleto Antico.**	P. VII, 11, P. III	1783, 1892, 1905.
N 21 E	**Plati**, *Gifoni,* Arena, Ciano, **Gerocarne**, Sorianello, **Soriano**, **Vazzano**, *S. Pietro di Maida.*	XXXIX	1659, 1783, 1905.
N 21 E	**Ferruzzano**, *Bovalino,* Ardore, **Gerace**, *Agnana,* **Grotteria**, Argusto, **Borgia**, **S. Floro**, Vincolise.	XXXVIII, also P. VII, 11	1783, 1894, 1905.
N 21 E	Precacore, Careri, Cimina, Antonimina, **Serra S. Bruno**, Brognaturo, Torre di Ruggiero, S. Vito sul Ionico. Cenadi, Amarone, **Settingiana**, Sorbo, S. Giovanni in Fiore.	Between XXXVIII and XXXIX	1783, 1905.
N 22 E	Aci S. Antonio, Fossa dell' Acqua, Malovrio, Cario, Le Aguzze, S. Guardia, Mangano, **Riposto.**	P. X	1865.
N 22 E	*Catania,* Acireale, S. Tecla.	P. X	1865.
N 22 E	**Messina**, *Amantea,* **Marano Marchesato**, *Rende.*	P. VII, 11	1886, 1905.
N 23 E	**Sinopoli**, **Rizziconi**, **Mileto**, **Monteleone.**	P. III P. VII, 11	1783, 1892, 1905.
N 23 E	Vallamidi, Cannavò, Terreti, *Langenadi,* **Bagnara**, **Palmi**, *Nicotera,* **Briatico.**	P. III	1783, 1892, 1905.
N 25 E	**Roccaforte**, **Cittanova**, **S. Giorgio Morgeto**, *Pizzoni.*	P. III	1783, 1894, 1905.
N 27 E	S. Teresa, Ali, Itala, Forte Spurio.	P. III	1894.
N 27 E	**Montebello**, **Delianuova**, **Scido**, **S. Georgia**, **Lubrichi**, **Iatrinoli**, **Feroleto**, **Plaizano**, **Laureana**, **Candidoni**, **Serrata**, **Francavilla**, Montesanto, **Feroleto Antico**, *Serrastretta,* Panettieri.	XLIV	1783, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 27 E	Catania, Acireale, Messina.	P. IX, 4	1693.
N 30 E	Pisano, S. Venerina, Dagala, Fondo di Macchia, Mascali.	P. X	1865.
N 30 E	Misterbianca, Mascalucia, Trecastagne, Mascali.	P. X	1693.
N 31 E	Linera, S. Matteo.	P. X	1865.
N 32 E	Tarsia, Spezzano Albanese, Stazione Cassano.	P. VIII, 13	1886, 1887.
N 32 E	Montebello, Bagaladi, Molochio, Cittanova, S. Giorgio Morgeto, *Giffoni*, Amaroni.	XIX—XL	1783, 1905.
N 32 E	Salina, Delianuova, Radicena, Polistena (?), *Limpidi*, Acquaro, Soriano, S. Nicola, Cortale, *Tiriolo*.	P. III, P. VII, 11	1783, 1892, 1894, 1905.
N 33 E	*Reggio*, Gioia Tauro, Monteleone, Pizzo.	P. III, P. VII, 11	1783, 1886, 1892, 1894, 1905.
N 33 E	*Reggio*, S. Caterina di Reggio, S. Giovanni di Gallico, Diminniti, *S. Roberto*, Palmi, Rosarno, S. Pietro di Mileto, Calabrò, S. Gregorio, Zammarò, Piscopio, Stefanaconi, S. Onofrio, Feroleto Antico, *Serrastretta*, Carlopoli.	44	1783, 1894, 1898, 1905.
N 33 E	*Gioia Tauro*, *S. Calogero*, S. Constantino Calabro, Longobardi, Pizzo.	30	1783, 1905.
N 33 E	*Giarre*-Riposto, *Taormina*, S. Teresa, Guidomandri, Tremestieri, Messina, Ganzirri.	P. X, P. IX, 6, P. III	1818, 1823, 1865, 1892, 1894, 1898.
N 33 E	*Paola*, Tarsia, Spezzano Albanese.	P. VIII, 13	1835.
N 34 E	*Aderno*, *Castroreale*, S. Filippo.	P. IX, 4	1693.
N 36 E	Laureana, Serrata, Monterosso, *Polia*, *Tiriolo*, *Gimigliano*, Sorbo, Cerenzia.	P. VII, 11	1783, 1886, 1905.
N 37 E	Lipari, Panaria, Stromboli, *S. Sosti*, Acquaformosa, S. Basile.	P. III, V, 1, VII, 10	1892, 1905.
N 37 E	Etna, *Castiglione di Sicilia*, *Francavilla*.	P. X	1893.
N 37 E	Sambiase, Platania, Decollatura, Bianchi.	10	1638, 1905.
N 38 E	Catania, Aci Castello, Aci Trezza.	P. IX, 4	1693.
N 39 E	Cropani, Marcedusa, S. Mauro Marchesato, Rocca die Neto.	P. VIII, 14	1832.
N 40 E	Altilia, *Marzi*, S. Stefano di Rogliano, *Mangone*, Longobucco.	P. VIII, 15, 13	1783, 1870.
N 41 E	Pontegrande, Sellia, Petilia Policastro, Altilia, Casabona, Melissa.	P. VIII, 14	1832.
N 41 E	Zaffarana, Cancellieri, Torre del Filosofo, S. Giovanni, Mascali.	P. X	1865.
N 42 E	Precacore, S. Agata di Bianco, Casignana, *Bovalino*, Candojanni, Caulonia, Placanica.	XLIV	1783, 1905.
N 42 E	S. Agata, *S. Sosti*, Acquaformosa, Lungro, Castrovillari.	P. VII, 10	1887.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 43 E	*Mongrassano, Cervicati,* Stazione Cassano.	P. VII, 10	1887.
N 44 E	*Bronte,* Randazzo, *Roccella, Valdemone, S. Lucia di Meri, S. Martino.*	P. IX, 1, 3, 4, 5, 6, P. X	1783, 1818, 1886, 1893, 1894, 1898.
N 45 E	Amantea, Cosenza, *Zumpano,* Rossano.	P. VIII, 12	1870.
N 45 E	Etna, Mandanici, Larderia, Zaffaria, Messina, Mileto, Calabrò, *Tiriolo.*	P.VII,11,IX.1	1886, 1898.
N 46 E	Regelbuto, *Bronte,* Randazzo, Novara, Valdina, Venetico, Bauso.	P. IX, 4	1693, 1892.
N 47 E	Bisignano, S. Demetrio, Macchia.	P. VIII, 13	1835.
N 49 E	Monteleone, *Curinga, S. Pietro di Maida,* Maida, *Tiriolo,* Fossato, Melissa.	P. VII, 11, VIII, 14	1892.
N 49 E	Riposto, Mosorrofa, Paracorio, Delianuova, Scido, Oppido Mamertino, Cittanova.	P. III, IV	1783, 1894, 1898, 1905.
N 51 E	'Etna, Linguaglossa, Ali, Guidomandri, Campo, Bagnara.	P. IV	1894.
N 52 E	Catanzaro, Simeria, Soveria, Belcastro, S. Mauro Marchesato, Scandali.	P. VIII, 14	1783, 1832, 1905.
N 52 E	*Carpanzano,* Bocchigliero, Mandatoriccio.	P. VII, 10	1897.
N 53 E	*Castroreale,* S. Lucia di Meri, Condrò, Valdina, Venetico, Bauso.	P. IX, 4	1693, 1783.
N 53 E	Vena, Triparni, Pizzo, Maida.	P. III	1783, 1894, 1905.
N 54 E	Belmonte Calabro, Domanico, *Dipignano, Spezzano Grande,* Longobucco, Cropolati, Calopezzati.	P. VIII, 13	1835, 1905.
N 54 E	Milazzo, *Ioppolo, Caroniti, Cessaniti,* Mantinio, Triparni, Pizzo, *Curinga, S. Pietro di Maida,* Maida, Marcellinara, Mesuraca, S. Severina, Rocca di Neto.	IV, V, also P. VIII, 14	1638, 1783, 1894, 1905.
N 55 E	*Bronte,* Malvagna, Messina, Palmi, Lauriano, Candidoni, S. Pier Fidele, *Dinami,* Limpidi, Acquaro, Arena, Torre di Ruggiero, Argusto, Patrizzi.	P.IX,1,VII,11	1783, 1886, 1894, 1905.
N 55 E	Aderno, Etna, *Reggio, S. Alessio,* Cosoleto.	P. IX, 4	1693, 1783, 1905.
N 56 E	Novaro, *Gioia Tauro,* Soriano, *Gasperina.*	P. III	1783, 1892, 1905.
N 56 E	Monteleone, Filadelfia, Cortale, Caraffa, Pontegrande.	P. III	1783, 1892, 1905.
N 56 E	Cetraro, S. Caterina Albanese, Stazione Cassano.	P. VII, 10	1887.
N 56 E	*S. Pietro di Nicotera,* Comparni, Vallefiorita, Papanici.	—	1783.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 57 E	Etna, S. Teresa, Terreti, Arasi, **Podargoni**, **S. Stefano**, **Delianuova**, **Pedavoli**, **Scido**, **S. Cristina**, **Nardo**, S. Caterina del Ionico.	45—XVIII,	1783, 1894, 1905.
N 57 E	Mandaradoni di Limbadi, *Filandari*, Larzona, *Ionadi*, Nao, **S. Constantino Calabro**, **Zammarò**, **Girifalco**, Catanzaro, Simerie, Soveria, **Marcedusa**.	25	1783, 1905.
N 57 E	S. Nicola di Orsigliadi, **Brivadi**, Gasponi, Drapia, Daffina, S. Giovanni di Parghelia, **Mandaradoni di Briatico**, *Potenzone*, **Briatico**, **Amato**, **Migliarina**, *Gimigliano*, Fossato, Petilia Policastro.	24	1783, 1905.
N 59 E	*Castroreale*, **S. Lucia di Meri**, **Rocca** Valdina, Calvaruso.	P. IX, 4	1693, 1783.
N 60 E	**Marano Principato**, **Castrolibero**, **Castiglione Cosentino**, Paludi, Crosia.	Near 4—I, II, also P. VIII, 13	1638, 1835, 1905.
N 60 E	**Cosenza**, *Zumpano*, *Lappano*, Longobucco.	P. VIII, 13	1783, 1835, 1905.
N 60 E	**Zaffarana**, Cancellieri, Monacelli, Macchia, *Giarre*, **Riposto**, Salina, S. Lorenzo.	P. IX, 6, P. X	1818, 1865, 1886, 1892.
N 60 E	*Fuscaldo*, *Lattarico*, S. Sofia, S. Demetrio.	Near 3 to near I	1905.
N 61 E	Amantea, *Lago*, Bocchiglieri, Cariati.	P. VII, 10	1887, 1905.
N 63 E	Fleri, Pisano, Linera, Mangano.	P. X	1865.
N 64 E	*Fuscaldo*, **Bisignano**, **Coregliano Calabro**.	P. VII, 10	1887, 1905.
N 64 E	*Monforte*, **Rometta**, Saponara Villafranca, **Seminara**, **Polistena**, **Cinquefronde**, Badolato.	P. IX, 5, P. VII, 11	1783, 1894, 1905.
N 65 E	*Paola*, **Montalto Uffugo**, Luzzi, Acri, Rossano.	P. VII, 10	1887, 1905.
N 65 E	**Randazzo**, Malvagne, Itala, *Langenadi*, **Delianuova**, **S. Cristina**.	P. IX, 1, P. III	1893.
N 65 E	**Patti**, *S. Martino*, Bauso.	P. III, P. IV	1898.
N 65 E	Pittarella, **Pedavigliano**, S. Giovanni in fiore, Verzino.	—	1638.
N 65 E	**Cortale**, Catanzaro, Cropani, Cutro, Cotrone.	P. VIII, 14	1783, 1832, 1894, 1905.
N 65 E	Etna, *Taormina*, S. Luca, Careri, Benestare, Candojanni.	47—XXVII, also P. IX, 4—6	1693, 1783, 1818, 1865, 1893, 1905.
N 66 E	*Scigliano*, Parenti, S. Giovanni in Fiore, Verzino, Ciro.	6, 7—III	1638, 1905.
N 67 E	*Castroreale*, **Rometta**, Saponara Villafranca, **Messina**, Villa S. Giovanni, **Scilla**, **Bagnara**, **Iatrinola**, **Radicena**, **S. Giorgio Morgeto**, Stilo.	P. IX, 5, P. IV	1783, 1894, 1898, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 67 E	*Roccella Valdemone,* **Calanna,** S. **Giorgio, Mammola, Grotteria.**	P. III, VII, 11	1783, 1894, 1905.
N 68 E	Vulcano (former crater), **Tropea, Briatico,** Cortale, Catanzaro.	P. III	1892, 1894.
N 68 E	Guardia Piemontese, **Torano Castello,** S. Demetrio, S. Cosimo.	P. VII, 10	1887.
N 68 E	**Riposto,** Melito, Staiti.	P. III, IV	1898.
N 68 E	Brivadi, Brattura, Caria, S. Giovanni di Parghelia. **Pizzo, Francavilla,** Filadelfia, **Girifalco.**	7	1783, 1905.
N 68 E	Salina, Sambiase, Nicastro, Cicale, Petilia Policastro, Roccabernarda, S. Severina.	—	1638, 1783, 1905.
N 68 E	*Catona,* Rosali, *S. Roberto,* **Acquaro di Sinopoli, Oppido Mamertino, Turgenadio, Molochio, Mammola, Grotteria,** Camini, Monasterace.	34,43—XIX, XX; also P. IV	1783, 1894, 1905.
N 69 E	S. Domenica, *Roccella Valdemone,* **Itala,** *Reggio,* Arasi, **Plati, Gerace, Siderno,** Roccella Ionica.	43—XXII	1783, 1893, 1894, 1905.
N 69 E	Mandanici, Guidomandri, *Reggio,* Arasi.	P. III	1898.
N 69 E	Etna, Piedimonte, Calatabiano, *(Taormina),* **Roccaforte,** Raghudi, Caraffa di Bianco.	P. IX, 6, P. III	1783, 1818, 1894.
N 69 E	Salo, Civita, Bongiardo.	P. X	1865.
N 69 E	Dipignano, S. Ippolito, Casole Bruzio, Scala Coeli.	P. VIII, 13	1835, 1905.
N 70 E	**Cosenza,** Rovella, *Celico.*	P. VIII, 12	1870.
N 73 E	Cortale, Bottricella, Stazione Roccabernarda, Stazione Isola-Capo Rizzuto.	Near VI	1895.
N 73 E	**Tropea, Parghelia,** *Zambrone,* Porto Salvo, **Pizzo,** Amarone.	22—X	1783, 1894, 1905.
N 74 E	**Naso, Milazzo, Polistena.**	P.III,P.VII,11	1783, 1892.
N 74 E	Lipari, **Tropea, Pizzo.**	P. VII, 11	1886.
N 74 E	**S. Lucia di Meri, Sampiero, Rometta. Messina,** Villa S. Giovanni, Solano, **S. Eufemia D'Aspromonte, Sinopoli, Acquaro di Sinopoli,** Cosoleto, **Tresilico, Oppido Mamertino,** Giojosa.	—	1783, 1886, 1894, 1905.
N 76 E	*Bronte,* **Linguaglossa,** *Taormina,* Montebello Amandolea, Bova, Bruzzano.	XXXIII—XXXIV	1783, 1892, 1894.
N 77 E	Paterno, Belpasso, Massannunciata, Aci Bonaccorsi, S. Antonio.	P. X	1693.
N 78 E	Pianopoli, *Gimigliano,* Pentone, Zagarise, Sersale, Andale, Belcastro, Macedusa, (Cotrone).	9	1783, 1905.
N 78 E	**Marano Marchesato,** *S. Pietro in Guarano,* Bocchigliero, Scala Coeli.	P. VIII, 13	1783, 1835, 1905.
N 78 E	**Randazzo,** *Francavilla,* S. Teresa, Motta S. Giovanni, Bagaludi, Roccaforte, Precacore, Bianco.	46—XXXII, also P.IX, 1; 4 P. III	1693, 1783, 1894, 1898, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 78 E	Alicuri, Filicuri, Panaria.	P. III, C. IX, 1	1892.
N 78 E	Militello, Tintori, Barcelona, Sampiero, **Rometta**, Saponara Villafranca, **Messina**, Villa S. Giovanni, **Sinopoli**, **S. Giorgia**, **Lubrichi.**	P. IX, 5	1783, 1893.
N 78 E	Nicosia, Troina, *Castiglione.*	P. IX, 4	1693.
N 79 E	*Paola, Rosa,* Longobucco, Cariati.	P. VII, 10	1887.
N 79 E	Diamante, Bonvicino, S. Donato di Ninea, Acquaformosa.	Near I	1905.
N 79 E	Magisano, Papanici, Cotrone.	P. VIII, 14	1832.
N 80 E	*Rende,* **Castiglione Cosentino**, Bocchigliero.	P. VII, 10	1887.
N 80 E	**Seminara**, **Iatrinola**, **Radicena**, Placanica, Stignano, Riace.	—	1783, 1894, 1905.
N 81 E	Aci S. Antonio, Aci S. Lucia, Acireale.	P. X	1865.
N 82 E	**Seminara, Cittanova, Mammola, Grotteria, Caulonia.**	XX	1783, 1894, 1905.
N 83 E	**Naso**, **Patti**, S. Filippo, Barcelona, Pozzo di Gatto, Meri, Condrò, Rocca Valdina, Saponara Villafranca, **Messina**, ***Fiumara,*** **Pedavoli**, **Scido**, **Gerace.**	XXV; also P. IX, 4, VII, 11	1693, 1783, 1823, 1892, 1893, 1894, 1898.
N 84 E	Salina, **Tropea**, **Parghelia**, **Maierato**, **Monterosso**, Centrachè, *Gasperina.*	20, 22—XII, XIII; also VII, 11	1783, 1886, 1905.
N 84 E	Paternò, Mascalucia, Tremestieri, S. Giovanni la Punta.	P. IX, 4	1693.
N 85 E	*Gizzeria, S. Pietro Apostolo,* S. Basile, Magisano, Cerva, Marcedusa, Cutro.	P. VIII, 14, P. III	1783, 1832, 1905.
N 86 E	**Castellace**, **Varapodio**, **Terranova**, Gioiosa Ionica.	31—XXIII	1783, 1905.
N 86 E	Montesanto, **Marcellinara**, Pontegrande, Simerie, Stazione Roccabernarda.	8, 9	1783, 1905.
N 87 E	*Falerna,* Platania, *Serrastretta,* Sorbo, Taverna, S. Giovanni di Taverna, Vincolise, Cerva, Marcedusa, Cutro.	6, 7—V, VI	1783, 1905.
N 87 E	Etna, Annunciata, Mascali.	P. IX, 6	1818.
N 89 E	Panaria, **Tropea**, **Monteleone.**	P. VII, 11	1892.

Bearings from northwest to southeast.

N 2 W	**S. Anna di Seminara**, **Mellicucca**, **Procopio**, **Sinopoli**, **Roccaforte.**	P. III	1783, 1894, 1905.
N 2 W	S. Sofia, *Celico, Spezzano Grande, Spezzano Piccolo, Pietrafitta,* Decollatura, Maida, Torre di Ruggiero.	Near XXV, also P. VIII, 15	1638, 1783, 1854, 1905.
N 2 W	**Briatico**, S. Calogero, **Plati.**	Near 15 and XXVI, also P. IV	1783, 1894, 1904.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 2 W	**Bisignano,** *Rose,* **Castiglione Cosentino,** *Zumpano,* Rovella, **Turzano,** *Marzi, Carpenzano,* **Scigliano, Pedivigliano,** Nicastro, *Curinga,* Spadola, **Serra S. Bruno,** Nardo.	XXIX, also P. VIII, 13	1638, 1783, 1854, 1905.
N 3 W	Panaria, Fornari, Novara, *Francavilla,* **Linguaglossa.**	P. IX, 1	1893.
N 4 W	Piedimonte, Mascali, *Giarre,* S. Tecla.	P. IX, 6	1865.
N 4 W	*Mongrassano, Cerzeto,* S. Benedetto, *Lago, Cleto,* Savuto, *Nocera Terinese,* Maierato, Gerocarne, Agnana.	XXXIII	1638, 1783, 1905.
N 4 W	Fleri, Via Grande, S. Giovanni la Punta.	P. X, IX, 4	1693.
N 4 W	Lungro Altamonte, *Torano Castello,* **Montalto Uffugo, Marano Marchesato, Marano Principato,** S. Mango d'Aquino.	P. VII, 10	1783, 1887, 1905.
N 6 W	**Bisignano,** *S. Pietro in Guarano, Lappano, Trenta,* **S. Stefano di Rogliano, Rogliano, Maida, Caulonia,** Roccella Ionica.	Near XXV, also P. VIII, 13	1783, 1854, 1905.
N 6 W	**Milazzo,** Pozzo di Gatto, *Taormina.*	P. IX, 2	1823.
N 6 W	**Briatico,** Vena, Larzone, **Comparni, Feroleto, Mellicucco, Polistena, Cittanova.**	P. IV	1783, 1892, 1894, 1905.
N 7 W	*Fuscaldo, Paola,* Belmonte Calabro, Amantea.	West margin of Cocuzzo	1783, 1905.
N 10 W	**Tropea,** *Nicotera,* **Drosi, Rizziconi, Tresilico, Oppido Mamertino.**	P. IV	1783, 1892, 1905.
N 11 W	*Orti,* **Mosorrofa,** Fossato di Calabria, Montebello.	XLI	1783.
N 11 W	Panaria, Barcelona, *Taormina.*	P. IX, 1	1893.
N 11 W	Terranova di Sibari, S. Demetrio, Acri, *Tiriolo.*	P. VIII, 13	1835.
N 12 W	**Parghelia,** *Zaccanopoli,* **Rosarno, Radicena, Plati,** *Natile,* S. Luca, S. Agata di Bianco, **Ferruzzano.**	XXXV	1783, 1894, 1905.
N 12 W	Villa S. Giovanni, **Gallina,** Vallamidi, Motta S. Giovanni.	XLIII	1783, 1894.
N 14 W	Valdina, Rocca Valdina, Monforte.	P. IX, 5	1783.
N 15 W	Randazzo, Etna, Massannunziata, Mascalucia.	P. IX, 4	1693.
N 15 W	**Montalto Uffugo,** *Rende,* **Castrolibero,** Altilia, *S. Pietro di Maida.*	P. VIII, 15	1638, 1783, 1854, 1905.
N 16 W	**Marano Marchesato. Marano Principato,** *Cerisano,* Mendocino, Domenico, *Grimaldi,* **Martirano,** Sambiase.	P. VIII, 15	1638, 1783, 1754, 1905.
N 16 W	Filicuti, Naso, Tartorici.	P. IX, 1	1893.
N 17 W	*Malvito, Rota Greca,* **S. Benedetto,** S. Vincenzo la Costa.	—	1638, 1783.
N 18 W	Salina, *Castiglione di Sicilia,* **Linguaglossa,** *Giarre.*	P. IX, 6	1892.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 19 W	*Zumpano,* Rovella, *Piani Crati, Figline Vegliaturo, Cellara, Mangone.*	P. VIII, 12	1638, 1783, 1870, 1905.
N 20 W	Scalea, Bonifati, Acquapesa, Savuto, *Gizzeria.*	West margin of Cocuzzo	1905.
N 21 W	S. Donato di Ninco, *S. Marco, Cervicati, Torano Castello, Marzi, Carpanzano,* Decollatura, *Gasperina.*	P. VII, 10	1783, 1887, 1905.
N 23 W	**Milazzo, S. Lucia,** S. Filippo.	P. IX, 4	1693.
N 23 W	*Lappano,* Rovito. *Pedace, Pietrafitta,* Panettieri, Carlopoli, Casole Bruzio, *Tiriolo.*	P. VIII, 13	1783, 1835.
N 24 W	**Monteleone, Piscopio,** *Limpidi, S. Giovanni di Grotteria,* Martone, **Gioiosa Ionica.**	P. VII, 11	1638, 1783, Febr.-April 1886, 1905.
N 24 W	S. Giovanni in Fiore, Petilio Policastro, **Marcedusa.**	P. VIII, 14	1832.
N 24 W	**Patti,** *Castiglione di Sicilia,* **Linguaglossa,** Mascali, **Riposto.**	41—XXVI, P. IX. 4, 3, 6, P. X	1693, 1783, 1818, 1865, 1886, 1892, 1893, 1894.
N 25 W	**Palmi, Mellicucca, Procopio, Acquaro di Sinopoli, Pedavoli, Delianuova, Paracorio.**	28	1783, 1894, 1905.
N 25 W	Alicuti, Militello, *Bronte.*	P. IX, 1	1892.
N 25 W	Rossano, Altilia, S. Mauro Marchesato.	P. VIII, 14	1832.
N 26 W	S. Lorenzo Belizzi, Corigliano Calabro, Longobucco.	P. VIII, 13	1835.
N 28 W	**S. Benedetto, Rende, Dipignano,** *Paternò, Marzi.*	P. VIII, 13	1638, 1835, 1905.
N 28 W	Belvedere Marittima, Cetraro, Acquapesa, *Paolo,* Martirano, Nicastro, Cortale, Girifalco, Amaroni, Vallefiorita, Montepaone.	Near XVII, also P. VIII, 15	1638, 1783, 1854, 1905.
N 29 W	Castrovillari, S. Lorenzo della Valle, S. Demetrio, Cropani.	P. VIII, 14	1832.
N 30 W	Scalea, Bonvicino, *S. Fili,* **Marano Marchesato, Marano Principato, Pedivigliano,** Decollatura, **Borgia.**	XIII—XIV	1638, 1905.
N 30 W	Filicuri, Montalbano, *Castiglione di Sicilia,* Piedimonte.	P. IX, 1	1893.
N 30 W	Stromboli, *Fiumara,* Bagaladi, S. Lorenzo.	P. IV	1783, 1892.
N 32 W	**Bagnara,** Africo, Casalbuono, Staiti.	30, 31—XXXV, XXXVI	1783.
N 33 W	S. Agata, *Rota Greca,* **Montalto Uffugo, Cosenza,** *Mangone,* Panettieri, Carlopoli, Cicala, *Gimigliano,* Catanzaro.	XI, also P.VIII. 12, 14, P. VII, 11	1638, 1783, 1832, 1870, 1886, 1887, 1894, 1905.
N 33 W	Alicuri, **Randazzo, Zaffarana.**	P. X	1892.
N 33 W	**Drosi, Rizziconi, Iatrinoli,** Benestiari, Bovalino.	25—XXXII	1783, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 34 W	*S. Fili,* **Marano Marchesato, Marano Principato,** Carolei, Belsito, *Carpanzano,* Migliarina, **Marcellinara Settingiano.**	P. VIII, 14	1638, 1783, 1854, 1905.
N 34 W	Fiumefreddo, **Aiello, Cortale, Girifalco,** *Gasperina,* Soverato.	P. IX, 6, XV, XVI	1638, 1659, 1783, 1892, 1905.
N 34 W	Longobucco, Cerenzia, S. Mauro Marchesato, Cutro.	VI, VII	1783, 1905.
N 36 W	Verbicaro, *S. Caterina, Torano Castello.*	P. VII, 10	1887.
N 37 W	Filicuri, Tripi, Novara, *Taormina.*	P. IX, 1	1892, 1893.
N 37 W	Panaria, **Messina.** *Reggio,* Villamidi.	P. VII, 11	1783, 1892.
N 38 W	*Zambrone, Potenzone, S. Cono, Cessaniti,* **Nao, Calabrò, Mellicucca.**	17—XXVI	1659, 1783, 1905.
N 38 W	Alicuri, **Naso,** *Giarre.*	P. IX, 1, 6	1892.
N 38 W	*Castroreale,* Mandanici, **S. Teresa.**	P. IX, 4	1898.
N 39 W	Bocchigliero, Verzino, Zigne, Rocca di Neto, Cotrone.	Northeast of Sila	1638.
N 39 W	**Tropea,** Gaspone, **Moladi, Candidoni, Mammola.**	P. VII, 11	1783, 1894, 1905.
N 40 W	Baccuia, Floresta, Malvagne, **Linguaglossa,** Piedimonte.	P. IX, 1	1893.
N 40 W	Porto Salvo, **Monteleone, Piscopio, Gerocarne,** *Fabrizia,* **Nardo, Caulonia.**	15—XXIV	1659, 1783, 1905.
N 41 W	*Paola,* Domenico, *Scigliano, Tiriolo.*	P. VII, 10	1887, 1905.
N 42 W	Panaria, Forte Spurio, Ganzirri, Villa S. Giovanni, *Campo,* Sambatello, Diminiti, *Orti,* Arasi.	P. IV	1783, 1894.
N 42 W	Torre di Filosofo, **Monacella, Dogala,** Mangano.	P. X	1865.
N 42 W	Calvaruso, **Saponara Villafranca,** Montebello.	—	1894.
N 43 W	S. Demetrio, Roccabernardo, Cutro.	P. VIII, 14	1832.
N 43 W	*Paola, Carpanzano,* Catanzaro.	P. VII, 10	1887, 1905.
N 44 W	Scalea. *Malvito, S. Caterina Albanese, S. Marco, Petrona,* Belcastro.	VII	1905.
N 44 W	S. Demetrio. Altilia, S. Severina, Scandali, Papanice.	P. VIII, 14	1832.
N 45 W	*Nicotera,* **Anoia, Cinquefronde, Siderno.**	22—XXIX	1783, 1894, 1905.
N 45 W	**Rosarno, S. Giorgio Morgeto, Agnana.**	Near XXIX	1783, 1894, 1905.
N 45 W	Terranova di Sibari, S. Giorgio Albanese, Longobucco.	P. VIII, 13	1835.
N 45 W	S. Giovanni in Fiore, Roccabernada, Isola.	P. VIII, 14	1832.
N 46 W	**Vulcano, Milazzo,** Scaletta.	XLII, also P. IX, 1	1823, 1892, 1893, 1894.
N 46 W	*Mongrassano, Torano Castello, Rose.*	P. VII, 10	1887, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 47 W	*Gizzeria,* Montesanto, **Maida, Iacurso,** Amaroni, *Montauro.*	6—XIV	1638, 1783, 1905.
N 47 W	*Rende,* **Cosenza,** S. Ippolito.	P. VIII, 13	1735, 1783, 1886.
N 48 W	Carlopezzati, Crucoli, Ciro.	P. VIII, 14	1832.
N 48 W	S. Sofia, Cerenzia, S. Severina, Scandale, Papanice.	Between VI and VII	1783, 1905.
N 49 W	*S. Caterina Albanese, S. Marco,* Luzzi.	P. VII, 10	1887.
N 49 W	Panaria, *Fiumara, Langenadi,* **S. Alessio.**	P. IX, 2, 4	1892, 1783, 1905.
N 50 W	**Martirano,** Amato, **Marcellinara, Settingiano.**	XI	1783, 1905.
N 50 W	**Pizzo,** Maierato, Filogaso, Simbario, Brognaturo, Guardavalle.	12—XXI	1783, 1905.
N 51 W	**Briatico, Monteleone, Soriano.**	P. III	1783, 1892, 1905.
N 52 W	Lipari, Bauso, *Reggio.*	P. IV, IX, 1	1898.
N 53 W	Acquaformosa, Altamonte, Tarsia, S. Demetrio.	P. VII, 10	1887.
N 54 W	**Milazzo,** Sampiero, Melito.	P. IX, 5	1898.
N 54 W	*Fuscaldo, Rende,* **Cosenza, Apriigliano.**	P. VIII, 12, VII, 10	1638, 1783, 1870, 1887, 1905.
N 56 W	Stazione Sibari, Cariati.	P. VII, 10	1887.
N 58 W	**Milazzo,** Condrò, Monforte, Motta S. Giovanni.	P. IX, 5	1783, 1898.
N 58 W	Pozzo di Gatto, **S. Lucia di Meri,** Scaletta.	P. IX, 2	1823.
N 59 W	Panaria, **Bagnara, S. Eufemia d'Aspromonte, Delianuova.**	P. IV	1783, 1894, 1905.
N 59 W	**Iacurso,** Girifalco, *Squillace, Staletti.*	7—XIII	1638, 1659, 1783, 1905.
N 60 W	Villa S. Giovanni, Campo, **Calanna,** *Langenadi, Schindilifera,* Casalnuova, Bruzzano.	—	1783, 1894, 1905.
N 60 W	*Paola,* Donnici, *Piane Crati.*	P. VIII, 13	1783, 1835.
N 60 W	Acquapesa, **Montalto Uffugo, Castiglione Cosentino,** *S. Pietro in Guarano.*	P. VIII, 15	1783, 1854, 1905.
N 60 W	**Maida, Cortale.**	P. III	1638, 1783, 1892, 1894, 1905.
N 61 W	Aderno, Mascalucia, S. Agata.	P. IX, 4	1693.
N 61 W	Amato, *Tiriolo,* Catanzaro.	P. VII, 10	1783, 1887.
N 61 W	Crosia, Carlopezzati. Cariati.	P. VIII, 13	1835.
N 61 W	Salina, Lipari, Villa S. Giovanni, Campo, **S. Alessiò, Podargoni, Ferruzzano.**	—	1783, 1894, 1905.
N 62 W	Etna, Val del Bove, Mangone.	P. X	1865.
N 63 W	*Potenzone,* **Monteleone,** Pizzone, Serra **S. Bruno.**	P. III	1783, 1894, 1905.
N 63 W	Nicosia. Regelbuto, Motta S. Giovanni.	P. IX, 4	1693.
N 63 W	*S. Pietro di Amantea,* **Aiello, Martirano, Conflenti,** Decollatura, *S. Pietro Apostolo, Gimigliano.*	4—VIII	1638, 1783, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 63 W	Lungro, Spezzano Albanese, Terranuova di Sibari, Corigliano, Calabro, Paludi, Mandatoriccio. Scala, Coeli.	P. VIII, 13 VII, 10	1835, 1887.
N 64 W	*S. Sosti, Monfallone, Roggiano Gravina,* S. Sofia, Longobucco.	Between IV and V	1783, 1905.
N 64 W	**Tropea, Mileto** (?), *Arena.*	P. VII, 11	1886.
N 65 W	Pisano, Cario, S. Maria di Malati, S. Tecla.	P. X	1865.
N 65 W	Militello, Roccelle Valdemone, Malvagne.	P. IX, 1	1893.
N 67 W	Altamonte, S. Lorenzo della Valle, Paludi, Cropolati.	P. VIII, 13	1835.
N 68 W	S. Alfio, S. Giovanni, *Giarre.*	P. X	1865.
N 68 W	Vulcano (former crater), Campo, Calanna, *S. Alessio,* **S. Stefano.**	P. IX, 1	1783, 1894, 1905.
N 68 W	**Milazzo**, Roccella Valdemone, Rometta, **Gallina.**	P. IX, 5 P. III	1783, 1894.
N 69 W	Oliveri, Tintori, Furnari.	P. IX, 1	1893.
N 69 W	**Randazzo**, Piedimonte, Fiumefreddo.	P. IX, 6	1818.
N 69 W	*Lago,* Altilio, **Pedivigliano**, Panettieri, Albi, **Magisano, Zagarise**, Cropani, Bottricello.	VII	1783, 1905.
N 69 W	Salina, **Bagnara, Sinopoli**, Delianuova.	P. III. P. IV	1783, 1892, 1905.
N 69 W	Panaria, *Gioia Tauro, Rizziconi.*	P. III	1892.
N 70 W	*S. Marco,* **Bisignano**, Acri.	P. VII, 10	1887.
N 70 W	Acquaformosa, Rossano, Cariati.	P. VII, 10	1887.
N 72 W	Salo, Linera, Le Aguzze.	P. X	1865.
N 72 W	Lipari, **Procopio, Cosoleto, Lubrichi.**	P. III. VII, 11	1783, 1894, 1905.
N 73 W	Panaria, *Gioia Tauro,* S. Giorgio **Morgeto, Mammola**, Roccella Ionica.	P. III	1783, 1894, 1905.
N 73 W	Castrovillari, Cassano, Stazione Sibari.	P. VII, 10	1887.
N 74 W	**Marano Principato, Turzano**, Roccabernarda, Scandale, Cotrone.	—	1638, 1905.
N 76 W	Bonifati, ***Fagnano, Cervicati,* Bisignano**, Longobucco, Bocchigliero.	—	1638, 1905.
N 76 W	*Paola, S. Fili, Rende, Zumpano, Spezzano Grande.*	P. VIII, 15	1783, 1854, 1905.
N 76 W	*S. Sosti,* Tarsia, S. Cosimo.	P. VII, 10	1887.
N 77 W	*Cervicati,* **Bisignano**, Longobucco, Campana.	P. VIII, 13	1783, 1835, 1905.
N 77 W	*Castroreale,* Guidomandri, Motta, S. Giovanni.	P. IX, 4	1898.
N 77 W	S. Domenica, Maio, *Castiglione di Sicilia, Taormina.*	P. IX, 1	1893.
N 77 W	**Randazzo, Linguaglossa**, Calatabiano.	P. IX, 6 P. X	1783, 1818, 1886.
N 77 W	Nicosia, Aderno, Trecastagne, Acibonaccorsi, Aci Catena.	P. IX, 4 P. X	1693.
N 78 W	Sampiero, Monforte, *Reggio,* Mosorrofa, Casalbuona, **Ferruzzano.**	P. IX. 5 P. III	1783.
N 78 W	**Marano Marchesato**, Castrolibero, Cosenza, *Trenta, Pedace.*	—	1638, 1783, 1905.

Bearing	Communes and fractions thereof on line	Locations on maps or text figures	Years when movement has probably occurred on the plane
N 78 W	Fleri, Cario, S. Maria di Malati, S. Tecla.	P. X	1865.
N 79 W	Patti, Oliveri, *Castroreale,* Scaletta, Fossato, Amandolea.	P. IX, 1, 2	1783.
N 79 W	S. Benedetto, *Rose,* Verzino.	Near IV	1638, 1905.
N 80 W	Stromboli, *S. Cono,* Triparni, Monteleone, Stefanaconi.	P. III, IV	1783, 1894, 1905.
N 81 W	*Cerzeto, Torano Castello,* Longobucco.	3—III, IV	1783, 1905.
N 82 W	Tarsia, Corigliano Calabro, Crosia.	—	1835.
N 82 W	Stromboli, *Potenzone,* S. Onofrio.	—	1894, 1905.
N 83 W	Briatico, Longobardi, Maierato, *Capistrano,* Chiaravalle Centrale, Argusto, Gagliato.	19—XV	1783, 1894, 1905.
N 84 W	*S. Marco,* Triparni, Monteleone, Stefanaconi, Torre de Ruggiero, Cardinale, S. Sostene.	20—XVI	1659, 1783, 1894, 1905.
N 84 W	Ganzirri, Scilla, Solano, Delianuova, Plati.	P. III	1783, 1894, 1905.
N 84 W	Etna, S. Giovanni, Riposto.	P. X	1865, 1886.
N 84 W	*Carolei, Dipignano,* Donnici, *Aprigliano.*	Near 4, 7, 15	1638, 1783, 1905.
N 84 W	*Fuscaldo,* Montalto Uffugo, Rose.	P. VIII, 15	1783, 1854, 1905.
N 85 W	Regelbuto, Nicolosi, Pedara, Trecastagne, Via Grande, Acireale.	P. IX, 4	1693.
N 86 W	Sanguineto, *Malvito,* Rossano, Crosia.	1—II	1905.
N 87 W	Baccuia, S. Pietro, S. Barbara, Tripi.	P. IX, 1	1893.
N 87 W	Macchia, S. Giorgio Albanese, Rossano, Crosia.	P. VIII, 13	1835.
N 88 W	Naso, Tintori, *Reggio.*	P. IX, 1	1893.
N 89 W	Lipari, Rosarno, Stilo.	P. IV, VII, 11	1898.
N 89 W	Guardia Piemontese, *Rota Greca, Latarico,* Longobucco, Scala Coeli.	—	1905.
N 89 W	Bisignano, Caloveto, Cariati.	P. VIII, 13	1835.
N 89 W	Valdina, Venetico, Saponara Villafranca, Messina.	P. IX, 5	1783.
N 89 W	Milazzo, *S. Martino,* Calvaruso, Villa S. Giovanni, *S. Roberto.*	P. IX, 5, P. IV	1783.
N 89 W	Zaffarano, S. Venerino, S. Leonardello.	P. X	1865.
N 89 W	Forte Spurio, Bagnara, Procopio, Oppido Mamertino, Siderno.	P. III	1783, 1894, 1905.
N 89 W	*Gigmigliano,* Cropani, Isola.	P. VII, 14	1832.

Seismic Geography of Etna.

The high seismicity of the mass of Etna is well known. The large area of the base of the cone — its diameter is more than 25 miles — offers the possibility of its study to determine if seismogenetic lines may be located within its mass. Upon the basement of sediments the average thickness of volcanic material appears to be

about one half a mile. The arrangement of certain of the parasitic craters in line betrays the position of lines of fracture in the crust, and the greater number of these do not appear to be radial with respect to the central cone. A notable instance of such alignment of craters is furnished by the chain of the Monti Segreta, Nocella, Pizzuta, Gervasi, Arso and Difeso; all in the vicinity of Nicolosi. Near and parallel to this chain is that of the Monti Mazzo, S. Leo, Rinazzi, Guardiola and Albano. The alignment of Monte Menardo, Monte Peloso and the Monti Isellati, and Monte Intrario, and other cones in their vicinity, is not open to question. A study of the map of Etna as a whole discloses the fact that other cones, and generally large ones, are in many instances located at or near the junction of chains of small parasitic craters, or of these with seismotectonic lines hereafter to be described.

The populous section of the Etna mass is upon its southern and eastern slope directed toward the sea. Here the density of population is very great and the villages are for large areas almost continous; as they are, in fact, on the similarly fertile seaward slopes of Vesuvius. Whereas the zones of damage from earthquakes are marked out in most districts only at those points where they intersect villages, it is here almost as though we had one continous city extending for many miles in either direction; so that there is the possibility of discovering lanes of destruction similar to the one already described at Monteleone from the earthquakes of 1783 and 1905.

The earthquake of 1865, which affected the area north of S. Tecla, south of Mascali, and between Zaffarana and the coast, seems to have furnished the desired illustration, as clearly indicated by the sketch map of Baratta[1]). This destructive area is outlined by dashed lines on the map of plate 8, on which the seismotectonic lines come into prominence. The principal intersections of seismotectonic lines within this district have been shaken also by other earthquakes. The seismotectonic line which connects Fleri, Pisano, Linera, and Mangano continues the most prominent chain of parasitic craters already referred to from the neighborhood of Nicolosi.

The map (plate X) further indicates the relatively high seismicity of the intersections of seismotectonic lines for other Etna districts; since the communes damaged by the seisms of 1693, 1818,

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1) *M. Baratta,* I terremoti d'Italia, p. 443. Compare with the large scale topographic map of Etna by the Italian Geological Survey.

1865, 1886, 1892, 1893 and 1894 have been plotted upon it. As a result of these earthquakes Zaffarana reported damage six times; Riposto, Linguaglossa, Acireale, Catania, and Paternò five times; while Taormina, Castiglione, Giarre, Nicolosi, Belpasso, Biancavilla, Aderno, Bronte and Randazzo were damaged four times. It is worthy of note that these communes with the exception of Zaffarana, — a most important intersection — are upon the borders of the Etna block and mainly located on lineaments which have been described.

The Distribution of Brontidi.

Italian seismologists are entitled to the credit for having solved the problem of origin of the mysterious rumblings which in Holland have been known as *mistpoeffers*, in India as *Barisal guns*, and in Italy have most frequently been called *marina*. Cancani has shown [1]) that these rumblings have been heard in the *paese* sometimes at frequent intervals throughout the day or night (generally the latter when other sounds are hushed), and that they are not the distant roaring of the sea as at first supposed, but proceed from the earth. He has ascribed them to movements differing only in intensity from those which produce earthquakes. A considerable literature has recently accumulated upon them, for a review of which the reader is referred to the preceding paper.

A most extensive questionnaire instituted by the *Ufficio Centrale di Meteorologia e Geodinamica* with the aid of its great corps of correspondents, has been fruitful of results, and these are now being edited for publication by Professor *Alippi*. The initial paper upon the distribution of these rumblings, which will probably come into the science under *Alippi's* recent name of *brontidi* (like thunder), was the result of studies made through extended enquiry among the *contadini* of northwestern Calabria [2]). The list of communes from which they have been reported, reads like the report of damage after a Calabrian earthquake; for the villages reported are those of evil reputation seismically speaking — communes which have been repeatedly damaged by earthquakes. We have plotted them upon a geological sketch map of the district (Fig. 3) and it at once appears

1) *A. Cancani,* Rombi sismici. Boll. della Soc. Sismolog. Ital., vol. 7, 1901—1902, pp. 23—47.

2) *Tito Alippi,* I mistpoeffers calabresi. Boll. della Soc. Sismolog. Ital., vol. 7, 1901—1902, pp. 9—22.

that they are arranged in lines — the seismotectonic lines of the province. *Alippi* has indeed ascribed the *brontidi* to movements on fault planes — the faults of the upper and lower Crati valley as these have been determined by *Cortese* — but these planes are not located with much definiteness, and in any case can represent but a part of

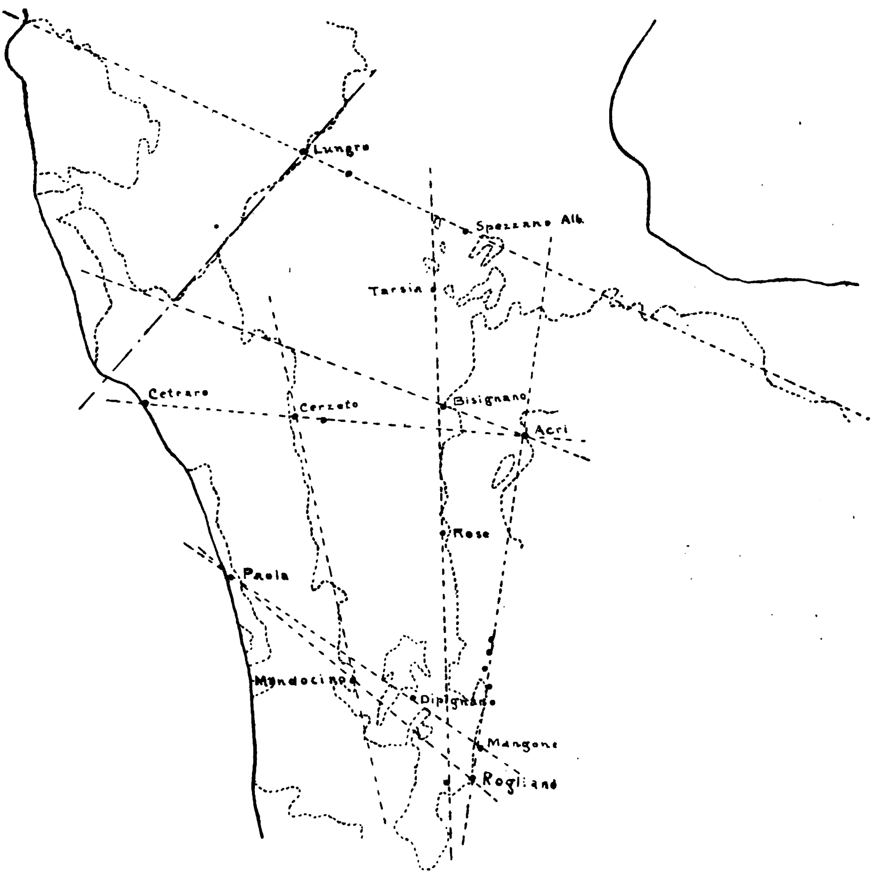

Fig. 3.

Sketch map to show the distribution of *brontidi* in Northern Calabria.

the fault system of the district. The tendency of the brontidotectonic lines (seismotectonic lines revealed through the brontidi) to follow geological contacts and other earth lineaments, is apparent from the map — as it is also that intersections come into prominence. Cancani early in the study of these phenomena suggested the possi-

bility of mapping them with the aid of microphones, and the map affords some promise that this method might yielt positive results.

The brontidi appear to be caused by the slow settling of orographic blocks with resultant vibrations within their marginal zones — vibrations which have a low pitch and an intensity sufficient only to be perceived by the unaided ear when in their immediate vicinity.

Distribution of habitual epicenters.

The recent appearance of a masterly work by de Montessus upon the distribution of earthquakes in relation to geological structures [1]) has opened a wide field for investigation. His many maps upon which the habitual epicenters have been located, examined in the light of studies made in New England and in Calabria disclose the fact that the more prominent epicenters lie at the intersections of lines of other epicenters, and likewise the intersections of the most prominent earth lineaments [2]). This has been illustrated especially by the maps of the British Isles, the Greater Antilles, Switzerland, Northwestern Europe, etc. The Count de Montessus has kindly computed by his method (with utilization of the latest data) especially for this paper the epicenters within the region here under consideration; and the results appear upon plate 10. The more prominent of the habitual epicenters the author has connected by dotted lines, and it appears that in a general way these correspond to certain of the seismotectonic lines of the region. The map thus affords tectonic data much the same in kind but of less detail than the seismotectonic maps already referred to. When the scale of the map is small, however, the results which are yielded by maps of habitual epicenters are usually sufficient to indicate the main lineaments; since epicenters, however artificial their nature, are certain to be near localities of high seismicity. Earthquake data being now so largely available in terms of epicenters, it is fortunate that these can be used directly to obtain important facts concerning structural geology.

Comparative orientation of different geotectonic systems.

The attempt has now been made to examine the system of structural planes which are developed within the rocks of the South-

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1) *F. de Montessus de Ballore,* Les tremblements de terre. Paris, 1906. pp. 471, pls. 3 and Figs. 89.

2) Seismic geology.

ern Italian Peninsula, Northeastern Sicily, and the Eolian Islands through the medium of: 1. the leading physiographic features — *grand lineaments*; 2. through the *network of joints*; 3. through the alignment of volcanic vents — *volcanotectonic lines*; 4. through the distribution of damage from earthquakes shocks — *seismotectonic lines*; and, 5. through the distribution of *habitual earthquake epicenters.*

It remains to compare the different systems of lines or directions as respects the relative orientation of the systems thus independently derived. This has been done in the following table. That a general correspondence in orientation exists will, it is thought, be apparent. The lack of precision in the measurements of joint planes (to nearest five degree unit of compass dial) allows of only a general comparison, and while the errors of observation in the measurement of the directions of the other elements are probably from two to three degrees in some instances, they are generally much less. The data contained in the table are graphically set forth on plate 2.

Comparative table showing the orientation of tectonic

Bearings northeast

Grand lineaments (numbers in parenthesis refer to plate V, Fig. 1)			Observed joint planes (measured to nearest five degree interval of compass dial)	
bearing	Nr.	Designation of lineament	bearing	Nr.
N 1° E	2	East margin of Sila mass (29). West margin of Sila mass (18)	N 1° E	1
—	—	—	*N 3° E*	15
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 8° E	36
—	—	—	—	—
—	—	—	—	—
—	—	—	N 11° E	3
—	—	—	—	—
—	—	—	*N 13° E*	12
—	—	—	N 15° E	6
—	—	—	—	—
—	—	—	—	—
—	—	—	N 18° E	8
—	—	—	—	—
N 21° E	1	Nicotera-Bagnara coast (23)	—	—
—	—	—	—	—
—	—	—	N 23° E	23
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 28° E	8
—	—	—	—	—
—	—	—	—	—
—	—	—	N 31° E	12
N 32° E	1	Taormina-Messina coast (19)	—	—
—	—	—	N 33° E	18
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
N 38° E	1	Cap Bonifati-Castrovillari Triassic-border (6)	*N 38° E*	29
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 43° E	26

planes in Calabria and northeastern Sicily.

and southwest.

Volcanotectonic planes (shown on small map of plate III)			Seismotectonic planes (shown on plate III)			Lines of epicenters, from data by de Montessus (shown on pl. XII)	
bearing	Nr.	Volcanic vents aligned	bearing	Nr.	Recorded times shaken	bearing	Nr.
—	—	—	N 1° E	11	28	*N 1° E*	2
—	—	—	N 3° E	1	4	—	—
N 4° E	1	Banco di Madrepora, Epomeo, Rocca Monfina	—	—	—	—	—
—	—	—	N 5° E	1	1	—	—
—	—	—	N 6° E	1	1	N 6° E	1
N 7° E	2	Linosa, Ustica, Ventotene. Etna, Stromboli	*N 7° E*	3	7	N 7° E	1
—	—	—	*N 8° E*	2	6	—	—
—	—	—	*N 9° E*	3	6	—	—
—	—	—	N 10° E	2	4	N 10° E	1
—	—	—	N 11° E	1	1	N 11° E	1
N 12° E	1	Ferdinandea, Ustica, Roccamonfina	N 12° E	1	1	—	—
—	—	—	—	—	—	N 13° E	1
—	—	—	N 15° E	1	5	—	—
—	—	—	*N 16° E*	4	7	—	—
—	—	—	N 17° E	1	1	—	—
N 18° E	1	Submarine eruption 1891, Roccamonfina	N 18° E	1	3	—	—
—	—	—	N 19° E	1	1	—	—
—	—	—	N 21° E	5	12	—	—
—	—	—	*N 22° E*	3	4	—	—
—	—	—	*N 23° E*	2	6	—	—
N 24° E	1	Pantelleria, Ustica, Vesuvius	—	—	—	—	—
—	—	—	N 25° E	1	3	—	—
—	—	—	N 27° E	3	4	—	—
—	—	—	—	—	—	—	—
N 29° E	1	Banco di Madrepora, Vulcano, Stromboli	—	—	—	—	—
—	—	—	N 30° E	2	2	N 30° E	3
—	—	—	N 31° E	1	1	—	—
—	—	—	N 32° E	3	8	—	—
N 33° E	1	Linosa, Lipari, Panaria, Stromboli	N 33° E	5	18	—	—
—	—	—	N 34° E	1	1	—	1
—	—	—	—	—	—	N 35° E	—
—	—	—	N 36° E	1	3	—	—
—	—	—	N 37° E	3	5	—	—
—	—	—	N 38° E	1	1	—	—
—	—	—	N 39° E	1	1	—	—
—	—	—	N 40° E	1	1	—	—
—	—	—	N 41° E	2	2	—	—
N 43° E	1	Linosa, Banco di Madrepora, Etna	N 43° E	1	1	—	—

Grand lineaments (numbers in parenthesis refer to plate V, Fig. 1)			Observed joint planes (measured to nearest five degree interval of compass dial)	
bearing	Nr.	Designation of lineament	bearing	Nr.
—	—	—	—	—
—	—	—	N 45° E	6
—	—	—	—	—
—	—	—	—	—
—	—	—	N 48° E	20
—	—	—	—	—
—	—	—	—	—
—	—	—	N 51° E	3
N 52° E	1	West margin crystalline Filadelfia and Peloritani masses (18)	—	—
—	—	—	N 53° E	39
—	—	—	—	—
—	—	—	—	—
—	—	—	N 56° E	1
—	—	—	—	—
—	—	—	*N 58° E*	10
—	—	—	—	—
—	—	—	—	—
—	—	—	N 61° E	1
—	—	—	—	—
N 63° E	1	Vaticano northwest coast (17)	*N 63° E*	10
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 68° E	2
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 73° E	3
—	—	—	—	—
N 76° E	1	Aspromonte schist-gneiss contact (27)	—	—
N 77° E	1	Line of mud volcanoes and sulphur springs from Paternò to Siculiana	—	—
—	—	—	*N 78° E*	9
—	—	—	—	—
—	—	—	—	—
—	—	—	N 81° E	23
—	—	—	—	—
N 83° E	1	Sicilian north coast (28)	—	—
—	—	—	—	—
—	—	—	N 85° E	8
—	—	—	—	—
—	—	—	—	—
—	—	—	N 88° E	2
—	—	—	—	—

Volcanotectonic planes (shown on small map of plate III)			Seismotectonic planes (shown on plate III)			Lines of epicenters, from data by de Montessus (shown on pl. XII)	
bearing	Nr.	Volcanic vents aligned	bearing	Nr.	Recorded times shaken	bearing	Nr.
—	—	—	N 44° E	1	6	—	—
—	—	—	N 45° E	2	3	N 45° E	1
—	—	—	N 46° E	1	2	—	—
—	—	—	N 47° E	1	1	—	—
—	—	—	—	—	—	—	—
—	—	—	*N 49° E*	1	5	—	—
—	—	—	—	—	—	N 50° E	1
—	—	—	N 51° E	1	1	—	—
N 52° E	1	Pantelleria, Salina, Stromboli	N 52° E	2	4	—	—
—	—	—	N 53° E	2	5	—	—
—	—	—	*N 54° E*	2	6	—	—
—	—	—	*N 55° E*	2	7	—	—
—	—	—	*N 56° E*	4	8	—	—
—	—	—	*N 57° E*	3	7	—	—
—	—	—	—	—	—	—	—
—	—	—	N 59° E	1	2	—	—
—	—	—	*N 60° E*	4	11	—	—
—	—	—	N 61° E	1	2	—	—
N 62° E	1	Pantelleria, submarine eruption near Siculiana	—	—	—	N 62° E	1
—	—	—	N 63° E	1	1	N 63° E	1
—	—	—	N 64° E	2	5	N 64° E	3
—	—	—	N 65° E	6	15	—	—
—	—	—	N 66° E	1	2	—	—
—	—	—	N 67° E	2	7	N 67° E	1
N 68° E	1	Pantelleria, Ferdinandea, Etna	*N 68° E*	6	12	—	—
—	—	—	*N 69° E*	5	11	N 69° E	1
N 70° E	1	Vulcano, pinnacle shoal	N 70° E	1	1	—	—
—	—	—	—	—	—	N 71° E	1
—	—	—	N 73° E	2	4	—	—
—	—	—	*N 74° E*	3	7	*N 74° E*	2
—	—	—	N 76° E	1	3	—	—
—	—	—	N 77° E	1	1	N 77° E	1
N 78° E	1	Epomeo, Procida, Vesuvius, Voltura	*N 78° E*	5	13	—	—
—	—	—	N 79° E	2	2	N 79° E	1
—	—	—	N 80° E	2	4	—	—
—	—	—	N 81° E	1	1	—	—
N 82° E	1	Alicuri, Filicuri, Panaria	N 82° E	1	3	—	—
—	—	—	*N 83° E*	1	7	N 83° E	1
—	—	—	*N 84° E*	2	5	N 84° E	1
—	—	—	N 85° E	1	3	—	—
—	—	—	N 86° E	2	4	—	—
—	—	—	N 87° E	2	3	—	—
—	—	—	—	—	—	—	—
—	—	—	N 89° E	1	1	—	—

Bearings northwest

Grand lineaments (numbers in parenthesis refer to plate V, Fig. 1)			Observed joint planes (measured to nearest five degree interval of compass dial)	
bearing	Nr.	Designation of lineament	bearing	Nr.
—	—	—	*N 2° W*	14
N 3° W	1	East margin of the Aspromonte (14)	—	—
—	—	—	—	—
N 5° W	1	West margin of the Aspromonte (20)	—	—
—	—	—	—	—
—	—	—	N 7° W	28
—	—	—	—	—
N 11° W	2	East margin of Cocuzzo mass (12). West margin of Cocuzzo mass (11)	—	—
—	—	—	N 12° W	2
N 14° W	1	Scalea-Belvedere coast (2)	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 17° W	9
—	—	—	—	—
—	—	—	N 19° W	2
—	—	—	—	—
—	—	—	—	—
—	—	—	N 22° W	8
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 27° W	4
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 32° W	7
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
N 37° W	1	Maida-Soverato line (8)	*N 37° W*	12
—	—	—	—	—
—	—	—	N 39° W	6
—	—	—	—	—
—	—	—	—	—
—	—	—	N 42° W	8
—	—	—	—	—
—	—	—	—	—
—	—	—	N 45° W	2
N 46° W	1	Northwest diagonal of Sila mass — geological contact (3). Approx. northeast margin of Sila mass (1)	—	—

and southeast.

Volcanotectonic planes (shown on small map of plate III)			Seismotectonic planes (shown on plate III)			Lines of epicenters, from data by de Montessus (shown on pl. XII)	
bearing	Nr.	Volcanic vents aligned	bearing	Nr.	Recorded times shaken	bearing	Nr.
N 2° W	2	Lipari, Vulcano, Etna. Bolsena, Tolfa, Pantelleria	*N 2° W*	4	14	—	—
—	—	—	N 3° W	1	1	N 3° W	1
—	—	—	N 4° W	4	8	—	—
—	—	—	—	—	—	—	—
—	—	—	*N 6° W*	3	8	—	—
N 7° W	2	Vesuvius, Salina, Etna. Albano, Palmarola, Ustica	N 7° W	1	2	—	—
—	—	—	—	—	—	N 10° W	1
—	—	—	N 11° W	2	2	—	—
N 12° W	2	Vico, Bracciano, Ustica, Banco di Madrepora, Trapani, Ferdinandea, Linosa	*N 12° W*	2	5	N 12° W	1
—	—	—	N 14° W	1	1	—	—
—	—	—	N 15° W	2	5	—	—
—	—	—	N 16° W	2	5	—	—
—	—	—	—	—	—	—	—
—	—	—	N 18° W	1	1	—	—
—	—	—	N 19° W	1	4	—	—
—	—	—	N 20° W	1	1	—	—
N 21° W	1	Vico, Bracciano, Palmarola, Pachino	N 21° W	1	3	—	—
—	—	—	—	—	—	N 22° W	1
—	—	—	N 23° W	2	3	—	—
—	—	—	*N 24° W*	3	13	—	—
—	—	—	N 25° W	3	5	—	—
—	—	—	N 26° W	1	1	—	—
—	—	—	—	—	—	N 27° W	1
—	—	—	N 28° W	2	4	—	—
—	—	—	N 29° W	1	4	—	—
—	—	—	N 30° W	3	5	N 30° W	1
—	—	—	N 32° W	1	1	—	—
N 33° W	1	Amiata, Bolsena, Vendere, Vico, Bracciano, Albano, Stromboli	*N 33° W*	3	11	N 33° W	1
—	—	—	*N 34° W*	3	11	N 34° W	1
—	—	—	N 36° W	1	1	—	—
—	—	—	N 37° W	2	4	*N 37° W*	2
—	—	—	*N 38° W*	3	5	N 38° W	1
—	—	—	N 39° W	2	4	—	—
—	—	—	N 40° W	2	4	—	—
—	—	—	N 41° W	1	2	—	—
—	—	—	*N 42° W*	4	7	—	—
—	—	—	N 43° W	2	3	—	—
—	—	—	N 44° W	2	2	—	—
—	—	—	*N 45° W*	3	10	—	—
—	—	—	—	—	—	—	—

Grand lineaments (numbers in parenthesis refer to plate V, Fig. 1)			Observed joint planes (measured to nearest five degree interval of compass dial)	
bearing	Nr.	Designation of lineament	bearing	Nr.
—	—	—	*N 47° W*	15
N 48° W	2	Cape Bonifati Cosenza line—geological contact (5). Nicotera-Giosa line (16)	—	—
—	—	—	N 49° W	1
—	—	—	N 50° W	2
—	—	—	—	—
—	—	—	N 52° W	8
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 57° W	7
—	—	—	—	—
—	—	—	—	—
—	—	—	N 60° W	1
—	—	—	—	—
—	—	—	*N 62° W*	11
N 63° W	1	Cape Suvero-Maida line (9)	—	—
—	—	—	N 64° W	1
—	—	—	—	—
—	—	—	*N 67° W*	11
—	—	—	—	—
—	—	—	N 69° W	1
—	—	—	—	—
—	—	—	N 72° W	5
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	—	N 77° W	10
—	—	—	—	—
—	—	—	N 79° W	1
—	—	—	—	—
—	—	—	—	—
—	—	—	N 82° W	5
N 83° W	1	Vaticano northeast coast (15)	—	—
—	—	—	—	—
—	—	—	N 85° W	1
N 86° W	2	Cocuzzo-Sila north margin (4). Cocuzzo-Sila south margin (10)	—	—
—	—	—	N 87° W	40
—	—	—	—	—
—	—	—	—	—
N 90° W	1	Melito-Cape Spartivento line (26)	—	—

Volcanotectonic planes (shown on small map of plate III)			Seismotectonic planes (shown on plate III)			Lines of epicenters, from data by de Montessus (shown on pl. XII)	
bearing	Nr.	Volcanic vents aligned	bearing	Nr.	Recorded times shaken	bearing	Nr.
—	—	—	N 47° W	2	6	N 47° W	1
N 48° W	1	Bolsena, Frosinone, Roccamonfia	N 48° W	2	2	—	—
—	—	—	N 49° W	2	4	—	—
—	—	—	N 50° W	2	4	N 50° W	1
—	—	—	N 51° W	1	3	—	—
N 52° W	1	Vulcano-Milazzo line	N 52° W	1	1	—	—
N 53° W	1	Tolfa, Albano, Vesuvius	N 53° W	1	1	—	—
N 54° W	1	Sassu (Sardinia), Ustica, Etna	N 54° W	2	6	—	—
—	—	—	N 56° W	1	1	—	—
—	—	—	—	—	—	—	—
—	—	—	N 58° W	2	3	—	—
—	—	—	N 59° W	2	7	—	—
—	—	—	*N 60° W*	4	12	—	—
—	—	—	*N 61° W*	4	7	—	—
—	—	—	N 62° W	1	1	—	—
—	—	—	*N 63° W*	4	9	—	—
—	—	—	N 64° W	2	3	N 64° W	1
—	—	—	N 65° W	2	2	—	—
—	—	—	N 67° W	1	1	N 67° W	1
—	—	—	N 68° W	3	6	—	—
—	—	—	*N 69° W*	5	8	N 69° W	1
—	—	—	N 70° W	2	2	—	—
N 72° W	2	Submarine eruption 1863, Ferdinandea, Nerita, Banco di Madrepora. Palmarola, Ponza, Ventotene, Epomeo	N 72° W	2	4	—	—
—	—	—	N 73° W	2	4	—	—
—	—	—	N 74° W	1	2	—	—
—	—	—	N 76° W	3	6	—	—
N 77° W	1	Roccamonfina, Voltura	N 77° W	5	9	N 77° W	1
—	—	—	N 78° W	3	5	—	—
—	—	—	N 79° W	2	3	N 79° W	2
—	—	—	N 80° W	1	3	—	—
—	—	—	N 81° W	1	2	—	—
N 82° W	1	Ustica, Filicuri, Salina	N 82° W	2	3	—	—
—	—	—	N 83° W	1	3	N 83° W	1
—	—	—	N 84° W	5	15	—	—
—	—	—	N 85° W	1	1	—	—
—	—	—	N 86° W	1	1	—	—
N 87° W	2	Pantelleria, Banco di Madrepora, Pachino. Tolfa, Bracciano, Martignano, Baccano	N 87° W	2	2	—	—
—	—	—	N 88° W	1	1	—	—
—	—	—	N 89° W	7	9	—	—
—	—	—	—	—	—	—	—

A survey of the above table indicates that the most noteworthy maxima ly near the meridian (N 1° E to N 2° W) and near the equatorial direction (N 84°—89° W). Secondary maxima are found near N 7° E, N 21° E, N 33° E, N 52°—57° E, N 62°—65° E, N 68°—69° E, N 77°—78° E, N 83°—84° E; and near N 33°—34° W, N 37°—38° W, and N 77° W. The primary maxima thus correspond to two of the four most prominent structural directions revealed through a comparison of those observed in the rocks of many sections of the United States [1]).

Rome, May 17th. 1906.

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1) See a paper entitled, "The correlation of fracture systems and the evidences for planetary dislocations within the earth's crust". Trans. Wis. Acad. Sci. etc., vol. 15, pp. 15—29 (Reprints issued August 1905 in advance of general publication).

Plate IV.

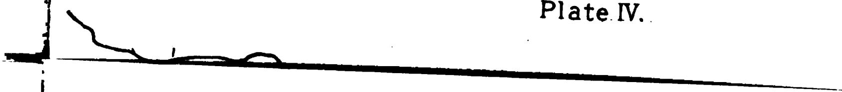
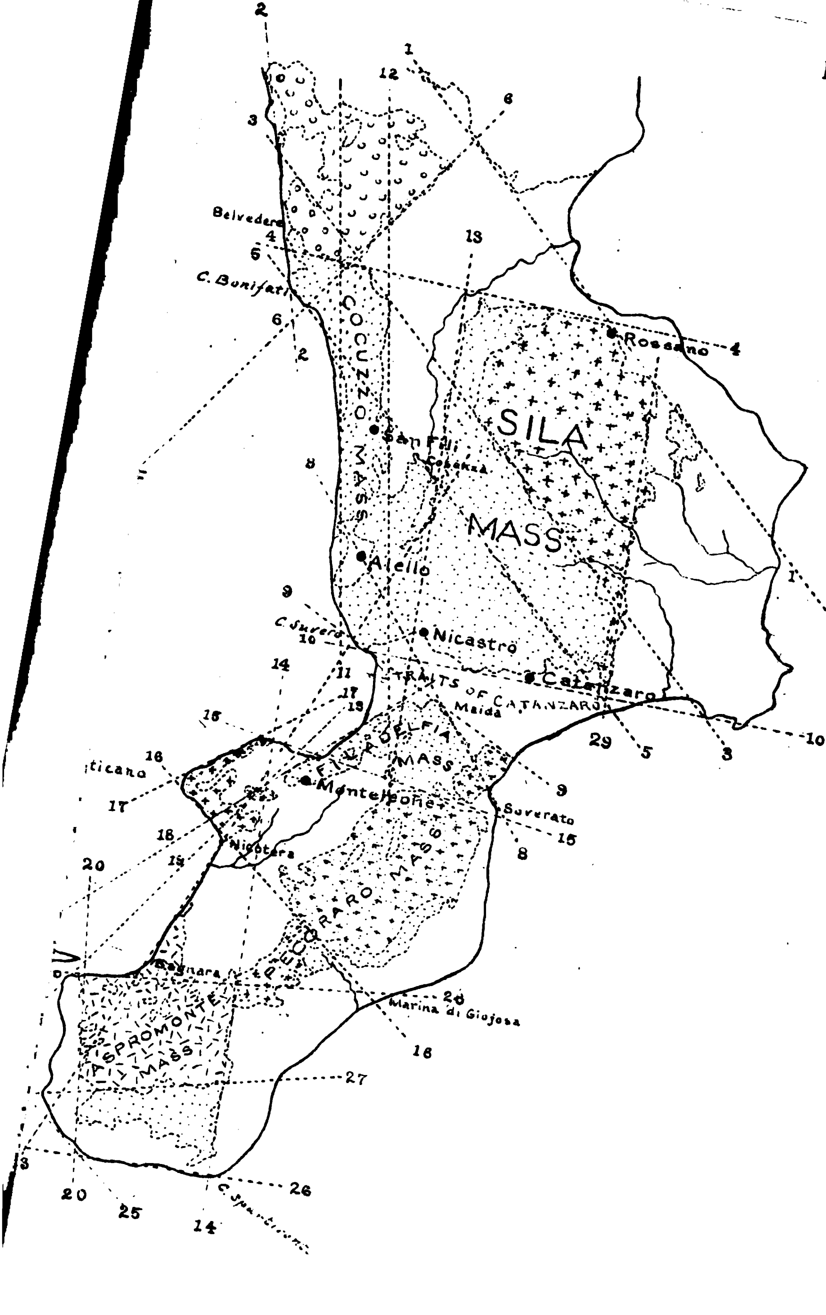


Plate V.



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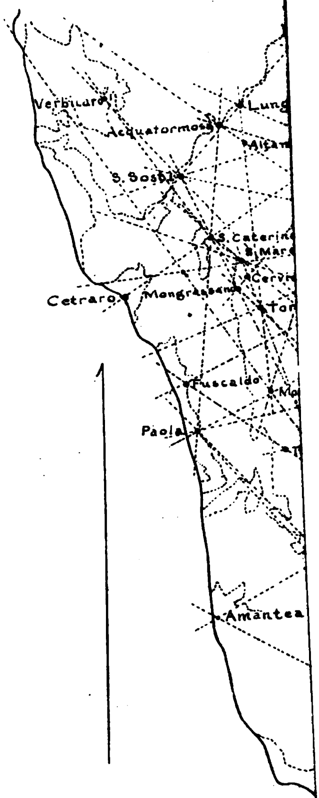

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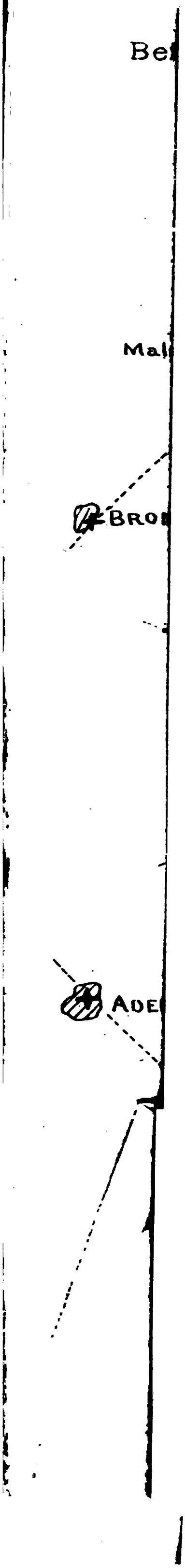

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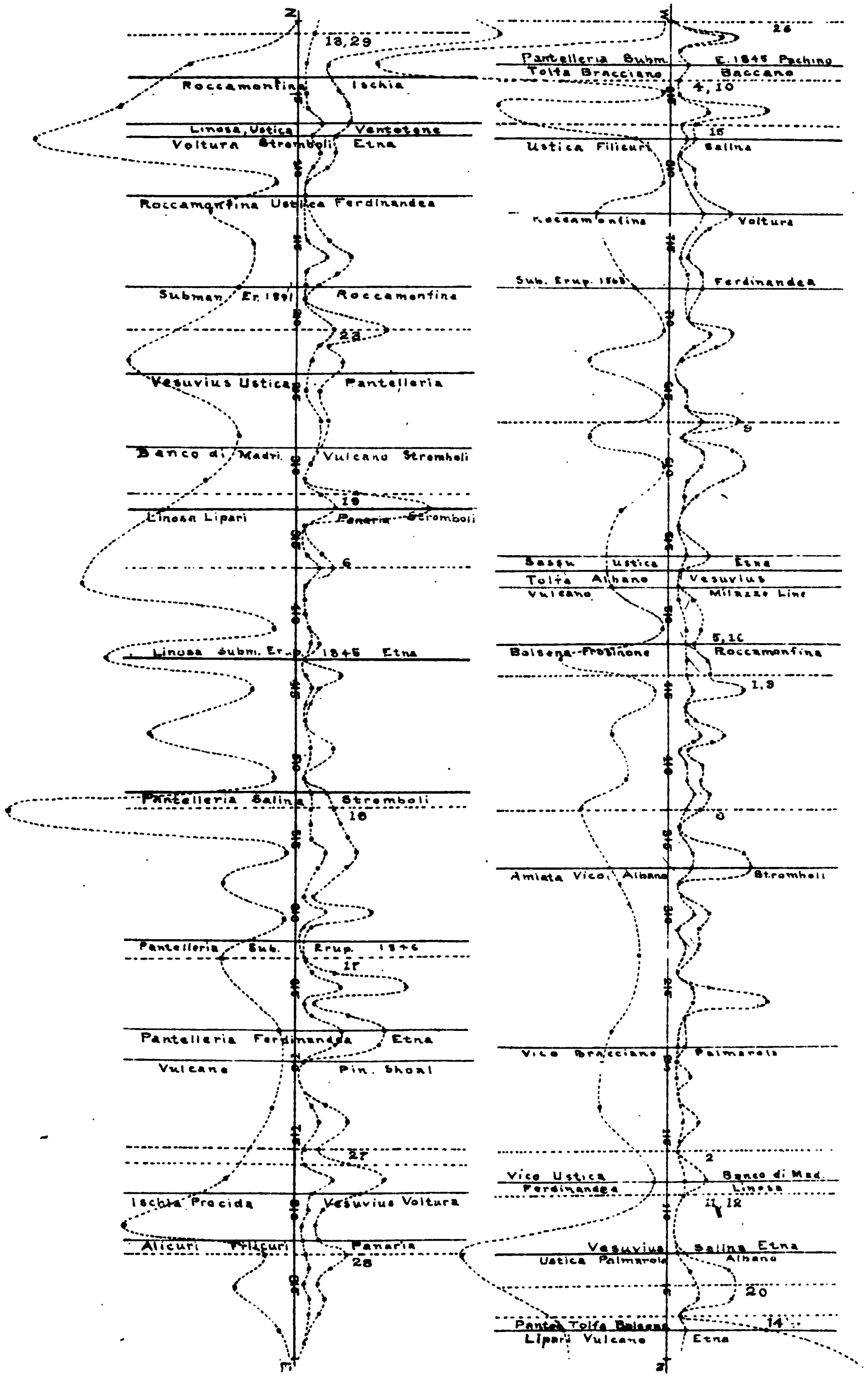

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With an Introduction

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